STUK-A207 / October 2004

NUCLEAR EMERGENCY RESPONSE PLANNING BASED ON PARTICIPATORY DECISION ANALYTIC APPROACHES

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Dissertation for the degree of Doctor of Philosophy to be presented with due permission of the department of Engineering Physics and Mathematics for public examination and debate in Auditorium E at the Helsinki University of Technology, Espoo, Finland on the 9th of December, 2004, at 12 noon.

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ISBN 951-712-909-2 (print)
ISBN 951-712-910-6 (pdf)
ISSN 0781-1705

Dark Oy, Vantaa, 2004

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Academic dissertation

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Nuclear emergency response planning based on participatory decision analytic approaches

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List of publications

The thesis is based on the following research publications which are referred to in the text by their Roman numerals, and a review of relevant literature.

I Sinkko K, Hämäläinen RP, Hänninen R. Experiences in methods to involve key players in planning protective actions in a case of nuclear accident. Radiation Protection Dosimetry 2004; 109 (1 - 2): 127-132.

II Hämäläinen RP, Lindstedt M, Sinkko K. Multi-attribute risk analysis in nuclear emergency management. Risk Analysis 2000; 20 (4): 455-467.

III Bartzis J, Ehrhardt J, French S, Lochard J, Morrey M, Papamichail KN, Sinkko K, Sohier A. RODOS: decision support for nuclear emergencies. Zanakis S. et. al. (eds.). In: Decision making: recent developments and worldwide application. Proceedings of DSI-Conference, Athens, Greece 1999: 381-395.

IV French S, Walmod-Larsen O, Sinkko K. Decision conferencing on countermeasures after a large nuclear accident: report of an exercise by the BER-3 of the NKS BER programme. Riso-R-676 (EN). Roskilde 1993.

V Sinkko K, Ikäheimonen TK, Mustonen R. Decision analysis of protective actions in forest areas. Lehto J. (ed.) In reprint: Cleanup of large radioactive-contaminated areas and disposal of generated waste. Copenhagen: TemaNord 1994; 567: 109-129.

VI Hämäläinen RP, Sinkko K, Lindstedt M, Ammann M, Salo A. Decision analysis interviews on protective actions in Finland supported by the RODOS system. STUK-A173. Helsinki: Radiation and Nuclear Safety Authority, 2000.

VII Ammann M, Sinkko K, Kostiainen E, Salo A, Liskola K, Hämäläinen RP, Mustajoki J. Decision analysis of countermeasures for the milk pathway after an accidental release of radionuclides. STUK-A186. Helsinki: Radiation and Nuclear Safety Authority, 2001.

Contribution of the author to the papers

I Principal author of the paper.

II This work was carried out with the support of the European Commission, Radiation Protection Research Action (DGXII-F-6), Contract FI4P-CT96-0053. The author was the co-ordinator of that project, the case study designer, responsible for consequence assessments, collaborator in the workshop design and co-author.

III Co-author of the paper.

IV This work was carried out with the support of the Nordic Nuclear Safety Research (NKS). The author was the case study designer, responsible for consequence assessments, collaborator in the workshop design and co-author.

V This work was carried out with the support of the Nordic Nuclear Safety Research (NKS). The author was case study designer, responsible for consequence assessments, interviewer and for decision analysis, and principal author.

VI This work was carried out with the support of the European Commission, Radiation Protection Research Action (DGXII-F-6), Contract FI4P-CT96-0053. The author was the co-ordinator of that project, the case study designer, responsible for consequence assessments, collaborator in the workshop design and principal author.

VII This work was carried out with the support of the Foodstuff Industry Pool, the National Emergency Support Agency and Valio Ltd. The author was the case study designer, responsible for consequence assessments, collaborator in the workshop design and notable author.

SINKKO, Kari. STUK-A-207. Nuclear emergency response planning based on participatory decision analytic approaches. Helsinki 2004, 60 pp. + Appendices 210 pp.

Keywords nuclear emergency management, countermeasures, decision-making process, decision support, multiattribute risk analysis

Abstract

This work was undertaken in order to develop methods and techniques for evaluating systematically and comprehensively protective action strategies in the case of a nuclear or radiation emergency. This was done in a way that the concerns and issues of all key players related to decisions on protective actions could be aggregated into decision-making transparently and in an equal manner. An approach called facilitated workshop, based on the theory of Decision Analysis, was tailored and tested in the planning of actions to be taken. The work builds on case studies in which it was assumed that a hypothetical accident in a nuclear power plant had led to a release of considerable amounts of radionuclides and therefore different types of protective actions should be considered. Altogether six workshops were organised in which all key players were represented, i.e., the authorities, expert organisations, industry and agricultural producers. The participants were those responsible for preparing advice or presenting matters for those responsible for the formal decision-making. Many preparatory meetings were held with various experts to prepare information for the workshops. It was considered essential that the set-up strictly follow the decision-making process to which the key players are accustomed. Key players or stakeholders comprise responsible administrators and organisations, politicians as well as representatives of the citizens affected and other persons who will and are likely to take part in decision-making in nuclear emergencies.

The realistic nature and the disciplined process of a facilitated workshop and commitment to decision-making yielded up insight in many radiation protection issues. The objectives and attributes which are considered in a decision on protective actions were discussed in many occasions and were defined for different accident scenario to come. In the workshops intervention levels were derived according justification and optimisation principles in radiation protection. Insight was also gained in what information should be collected or subject studied for emergency management. It was proved to be essential that information is in the proper form for decision-making. Therefore, methods and models to assess realistically the radiological and cost implications of different countermeasures

need to be further developed. In the consequent assessments, it is necessary to take production, economic, demographic and geographical information into account. Also, the feasibility and constraints of protective actions, such as logistics, require further investigation. For example, there seems to exist no plans in the EU or Nordic countries to dispose radioactive waste that may result from decontamination.

The experience gained strongly supports the format of a facilitated workshop for tackling a decision problem that concerns many different key players. The participants considered the workshop and the decision analysis very useful in planning actions in advance. They also expected a similar approach to be applicable in a real situation, although its suitability was not rated as highly as for planning. The suitability of the approach in the early phase of an accident was rated the lowest. It is concluded that a facilitated workshop is a valuable instrument for emergency management and in exercises in order to revise emergency plans or identify issues that need to be resolved.

The pros and cons of the facilitated workshop method can be compared with the conventional approaches. The general goal in all methods is that key players would be better prepared for an accident situation. All participatory methods, when practiced in advance, also create a network of key players. Facilitated workshops provide the participants with an forum for structured dialogue to discuss openly the values behind the decision. Stakeholder network can evaluate and augment generic countermeasures but all the possible and feasible protective actions cannot be justified and optimised in depth. The ranking of protective actions depends on weight put on an attribute and is thus dependent on the problem at hand.

Sinkko, Kari. STUK-A-207. Päätösanalyysiin perustuva sidosryhmien yhteinen vastatoimenpiteiden suunnittelu ydinonnettomuustilanteiden varalle. Helsinki 2004, 60 s. + Liitteet 210 s.

Avainsanat ydinonnettomuustilanteiden hallinta, säteilysuojelutoimen-piteet, päätöksentekoprosessi, päätöksenteon tuki, moniattribuutti riskianalyysi

Yhteenveto

Tämän työn tavoite on suunnitella säteilysuojelutoimenpiteitä ja kehittää menetelmiä, joilla voidaan evaluoida systemaattisesti ja kattavasti suojelutoimenpiteitä säteily- tai ydinonnettomuuksissa ja niiden ennakkosuunnittelussa. Toimenpiteiden suunnittelu tehdään siten, että kaikkien päätöksentekoon osallistuvien sidosryhmien näkökohdat otetaan huomioon tasapuolisesti ja avoimesti. Työssä on kehitetty ja testattu päätösanalyysiteoriaan perustuvaa päätösriihimenetelmää. Työ perustuu tapaustutkimusmenetelmään, jossa on oletettu onnettomuus ydinvoimalaitoksella. Sen seurauksena huomattava määrä radionuklideja on levinnyt ympäristöön ja joudutaan pohtimaan erilaisia suojelutoimenpiteitä. Tutkimuksen aikana järjestettiin kuusi päätösriihtä, joihin osallistui viranomaisia, eri alojen asiantuntijoita, teollisuuden ja maatalouden edustajia. Osallistujat olivat siten niitä, joiden tehtävä on valmistella toimenpidesuositus tai niitä, jotka esittelevät suosituksen päätöksentekijöille. Ennen jokaista päätösriihtä pidettiin asiantuntijoiden välisiä kokouksia, joissa valmisteltiin tietopaketti riiheen osallistujille. Tutkimuksessa pidettiin tärkeänä noudattaa samanlaista päätöksentekoprosessia, mihin sidosryhmät ovat tottuneet. Sidosryhmillä tarkoitetaan vastuullisia viranomaisia ja organisaatioita, politiikkoja ja väestön edustajia ja muita henkilöitä, jotka osallistuvat päätöksentekoon ydinonnettomuustilanteessa.

Päätösriihien realistinen perusluonne ja järjestelmällisyys, sekä sitoutuminen päätöksentekoon lisäsivät tietoa toimenpiteiden suunnittelusta. Toimenpiteiden tavoitteista, tekijöistä - attribuuteista - ja toimenpiteiden seurausvaikutuksista keskusteltiin monissa yhteyksissä ja ne määriteltiin mahdollisten uusien tilanteiden varalle. Toimenpidetasot arvotettiin riihessä kansainvälisten säteilysuojeluperiaatteiden mukaisesti (oikeutus- ja optimointiperiaatteet). Riihimenetelmä paljastaa myös mitä tietoa tulee valmistella tai tutkia päätöksiä varten. Ennen kaikkea tiedon tulee olla päätöksentekoon soveltuvassa muodossa, ei tieteellistä keskustelua. Havaittiin lisäksi, että on tarpeellista kehittää edelleen menetelmiä, jotka arvioivat paremmin ja totuudenmukaisemmin eri säteilysuojelutoimenpiteiden annossäästöt ja kustannukset. Seurausvaikutuksia

arvioitaessa on tarpeellista ottaa huomioon alueelliset tiedot kuten väestö-, elinkeino- ja tuotantotiedot. Lisäselvityksiä tarvitaan myös toimenpiteiden toteuttamiskelpoisuudesta. Havaittiin esimerkiksi, ettei ole olemassa tarkkoja suunnitelmia mihin radioaktiivisten jätteet loppusijoitettaan ja miten kuljetetaan joissakin toimenpiteissä tarvittavat suuret tavaramäärät.

Tehty työ vahvistaa näkemystä, että päätösriihimenetelmä soveltuu hyvin sellaisten päätösten valmisteluun, joihin osallistuu eri sidosryhmiä. Riihiin osallistuneet pitivät yleisesti riihtä ja päätösanalyysiä hyvin hyödyllisenä suunniteltaessa suojelutoimenpiteitä etukäteen. He myös arvioivat tämäntyyppisen lähestymistavan soveltuvan todelliseenkin onnettomuustilanteeseen, joskin soveltuvuus ei arvioitu niin hyväksi kuin etukäteissuunnittelussa. Menetelmän soveltuvuus ydinonnettomuuden varhaisvaiheen nopean päätöksenteon tueksi arvioitiin alhaisimmaksi. Voidaan tehdä johtopäätös, että päätösriihi on hyödyllinen menetelmä ydinonnettomuuksien hallinnassa ja varautumisessa. Se auttaa suunnittelua ja tunnistaa kehittämiskohteita.

Päätösriihen valo ja varjopuolet voidaan arvioida vertaamalla sitä muihin sidosryhmien välisessä työskentelyssä käytätettyihin menetelmiin kuten kuuleminen, neuvoa antavat lautakunnat ja suunnitteluryhmät. Kaikki nämä menetelmät, kun niitä harjoitellaan etukäteen, luovat sidosryhmien välisen verkoston. Päätösriihi tarjoaa osallistujille avoimen foorumin, jossa strukturoidun dialogin avulla keskustellaan päätöksen perusteista. Muissa menetelmissä voidaan arvioida ja kartuttaa geneerisiä toimenpiteitä, mutta kaikkia mahdollisia vaihtoehtoja ei voida oikeuttaa ja optimoida syvällisesti kuten riihessä. Toimenpiteiden luokittelu riippuu attribuuteille annettavista painoista ja on tapauksesta riippuva.

Contents

1 Introduction

The consequence spectrum of nuclear and radiological accidents, such as failure of a reactor, medical or industrial sources, has been estimated to be wide. Many accidents have no impacts offsite due to no or negligible release, some have far-reaching environmental consequences and very few might result in early deaths and other health effects off-site, such as increased cancer cases (NRC/CEC 1997; NRC 1975). The consequences of occurred accidents in Windscale (1957), in Kyshtym (1957), in the Three Mile Island (1979) and Chernobyl (1986) have also large variation (UNSCEAR 1988 and 2000). The consequences of an accident and intervention will depend substantially on the event, nuclide composition of the release and on the season (winter vis-a-vis the cultivation season). The choice of intervention measures is also linked to the legislation and living standard of the country potentially affected. Because of this diversity, and the constraints and deficiencies in consequence calculation tools in the past, international organisations have not been able to take into account all potential scenarios and all national circumstances. The recommended intervention levels have been based on reasoning or generic cost-benefit optimisation of protective actions which will most likely protect the population in an appropriate manner. Recommendations cover general and readily available countermeasures. For example, only withdrawal and substitution of contaminated foodstuffs have been considered. Detailed planning was seen as the duty of each individual country and deliberately left to national organisations.

Neither intervention planning nor the decision-making process can be developed from scratch in a nuclear emergency situation. In order to cope with any future accident, planning in advance both possible countermeasures and the decision-making process, developed both for the early and later phases, could ensure rational and transparent decisions. The importance of planning in advance and the need to develop a transparent decision-making process were clearly demonstrated after the Chernobyl (1986) and Coiania (1987) accidents. This study is a response to the international call for national planning in advance and for the development of the decision-making process in nuclear emergency management in order to be better prepared for any future nuclear accident.

Interventions affect various sectors of the society (primary production, industry, trade, population, consumers, clean-up workers etc.). There are different factors (radiological, economic, social, psychological etc.) that have to be taken into account when deciding on countermeasures (Allen et. al. 1996). The decisions are made under high uncertainties (French 1997). For example, the release assessments are very uncertain, the dose and the costs per individual can only be predicted, not be measured at the time of the decision, and wide variations are possible. Protective actions, as concerning society widely, are group decisions. Key players have often different views on the problem and the importance of relevant objectives.

Societal decisions are typically prepared in series of discussions, negotiations and meetings. The key players could be engaged in the decision-making process in various ways and often by the increased cost and complexity of the process (Mumpower 2001). The following citizen participation models are considered the most important to be reckoned with: advisory committees, planning cells, citizen juries, initiatives, negotiated rule making, mediation, compensation and benefit sharing and the Dutch study group (Renn et. al. 1995). The workshop proceedings of OECD/NEA (2001) also give many examples of how key players are involved in radiation protection. Participation is not aimed at replacing modern forms of representative democracy but should be an integrated part of the decision-making process (Renn et.al. 1995). Current practices range from the form where interested parties are only informed of the decision taken, to the form where the public based on a recommendation makes the decision (McDaniels et. al. 1999). Many protective actions in a nuclear emergency would not involve any compulsion and the final decision would be left to the population (French et. al. 1993, IV).

Individual participation methods have apparent advantages but some are also prone to shortcomings that have led to criticism (Gregory et. al. 1993; McDaniels et. al. 1999; Renn et. al. 1995). The decision might not be accountable and long-term planning might be neglected if the participants are not responsible for the implementation of the choice made. The working procedures and efficiency in the use of time in the group meetings have also often been considered to be poor (Hämäläinen and Leikola 1995; Sauri 2002; Susskind and Field 1996). Furthermore, key players might receive more information than they can utilise. Information could be in an unstructured form and not in the form needed in the decision-making process. The reported experience emphasises the importance of having relevant information, and clear procedures and methods for the decision-making process. Not all participatory methods articulate factors and judgement systematically and openly to be viewed by all people concerned.

Openness, transparency and participation by the key players are all important factors for balanced decision-making on public issues. Decisions should be understood, accepted and supported by both the population and decision-makers, not only be made in demographic order (Alho 2004). Those who must bear the harm and/ or benefits should have an opportunity to incorporate their objectives and values into the decision taken. The research in key players' and public involvement in environmental decisions have led to the conclusion that if the relevant parties are not engaged in the decision-making process the policy will fail and the final decision might ‘please almost no one and certainly infuriate many’ (Dubreuil et. al. 1999; Renn et. al. 1995; Susskind and Field 1996). The international organisations in radiation protection have recognised the importance of prompt, open and transparent decision-making based on scientific facts and social judgement (ICRP 2000; OECD/NEA 2002). They have emphasized that the basis for the decision must be perceived by the public, and all relevant factors concerning the decision should be considered in a rational manner.

The objective of this work in addition to planning countermeasures in advance is to develop methods to include the concerns of all key players openly and equally in the decision taken. The approach applied employs a group process where responsibility is placed on participants to assimilate information and to provide judgements. It has a clear structure based on the Decision Analysis.

Multi-attribute decision analysis provides a suitable framework for dealing with the complexity of the decision problem. It helps to clarify the objectives (‘to avoid radiation-induced cancer cases’) and to identify the attributes that can be used to measure the success of a strategy in achieving the objective (‘the radiation dose’). It provides a reasoning framework that intertwines the beliefs, preferences and value judgements of the key players and achieves a transparent ranking of the various strategies available.

Decision analysis techniques are not a new approach for solving societal problems. It has been applied to solve social and environmental decisions such as wastewater treatment and wilderness preservation problem (McDaniels 1996; McDaniels and Roessler 1998; Renn et. al. 1995). Gregory and Keeney (1994) organised a workshop to elicit stakeholder’s values and used them as the basis for creating an improved set of alternatives whether to permit development of a coal mine within an isolated pristine tropical rain forest. Marttunen and Hämäläinen (1995) applied decision analysis as an individual interactive computer supported interview method and involved large number of stakeholders in two river development projects. The papers by Apostolakis and Pickett (1998), Hämäläinen (1988, 1990, 1992) Hämäläinen and Karjalainen (1992), Keeney and von Winterfelt (1993) and Keeney (1980) are examples of studies of problems which deals with clean-up hazardous waste site, energy policy of nuclear power and management of nuclear waste. In the field of nuclear emergency management, decision analysis has been applied and facilitated workshops have been organised in various countries (Albrecht et. al. 1997; Aumonier and French 1992; Bartzis et. al. 1999, III; French et. al. 1996; International Chernobyl Project 1991; Sinkko 1991; Zeevaert et. al. 2001).

At the end of the 1980s the International Commission of Radiological Protection (ICRP) was revising its basic principles in radiation protection, and introduced the terms justification and optimisation. It was also recommended to apply decision-aiding techniques in radiological protection (ICRP 1989). International organisations have demonstrated how justification and optimisation could be applied to the planning of protective actions (OECD/NEA 1990; ICRP 1991; IAEA 1994). Because of their role, international organisations, for example the IAEA, aim to provide a benchmark against which national plans can be compared. A simple cost-benefit analysis approach has been adopted for that purpose.

At the same time, at the end of 1980 the author of this paper made a wide study on decision aiding techniques and its potential in countermeasure planning (Sinkko 1991; Gjörup et. al. 1992; Walmod-Larsen (ed.) 1994). The main issue was how the justification and optimisation could be done in practice. Gradually it becomes evident that multiattribute value or utility analysis of protective actions done by a scientist in emergency management community could not cover all aspects the decision. All relevant parties should come together and aggregate their views and judgements in rational manner in the decision. The format of facilitated workshop (also called decision conferencing) was seen as a promising format to do the planning equally and openly.

Six facilitated workshops were arranged to learn how to improve the decision-making process and plan protective actions in advance. The first workshops followed a two-day decision conferencing approach (French et. al. 1993, IV and 1996). Other forms of decision conferences have also been suggested for example the spontaneous decision conferencing concept, where the whole process can be accomplished in just a few hours and with minimal arrangements (Hämäläinen and Leikola 1995). In problems involving experts and higher level policy makers time is always limited. Therefore, this more concise type of approach was seen to be practical. In planning in advance shorter workshops necessitate extensive background information and preceding preparatory meetings but this kind of process was seen to comply with conventional emergency management. Another approach is the interview technique in order to analyse the decision situation from the perspective of different stakeholders. This approach was also considered useful in this study.

2 Review of literature

2.1 Intervention principles for radiation emergencies

Situations where radioactive materials exist or threaten to spread into the environment, and where protective actions are being considered to reduce the exposure, are called *intervention* situations (ICRP 1991). A nuclear or radiation accident, should it happen, or a prolonged exposure to radioactive materials of natural origin may call for intervention. In most situations, intervention cannot be applied to the source itself as in *practice,* e.g., operating a nuclear power plant where the structure of a source could be planned and the doses predicted. Intervention has to be applied to the environment, as the control of exposure pathways, or to individuals' freedom of action. In intervention protective actions have to be justified and optimised, whereas in practice the activity has to be *justified* and the radiation protection *optimised*.

The system of radiological protection defined by the International Commission on Radiological Protection (ICRP 2000) implies the protection of both individuals and the population. Firstly, the protection of individuals requires that 'deterministic health effects must be prevented and the individual risk of stochastic effects must be restricted'. Secondly, the system requires a wider justification to obtain the maximised health benefit for the greatest number of people by also considering the social and economic circumstances: 'all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account'. According to the ICRP, these statements could be linked to ethical principles, which link is considered important for societal acceptability of the system of radiological protection. In Operational Research it has also seen necessary to consider all ethical arguments in environmental decisions, and ethical systems to provide a rationale on the value of safety (Rauschmayer, 2001; Schulze 1980). However, the ICRP or any other equivalent international organisation has not explicitly referenced a specific ethical doctrine.

The basic principles for introducing protective actions in an intervention situation, recommended by international organizations (OECD/NEA 1990; IAEA 1994; ICRP 1991, 1993, 2000; IAEA/BSS 1996), are based on the justification and optimization of protective actions. They are intended to be generally applicable irrespective of the time elapsed, the distance from the source or the level of exposure. The basic principles recommended by the ICRP (1991) are as follows:

'The proposed intervention should do more good than harm, i.e., the reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention.'

'The form, scale, and duration of the intervention should be optimized so that the net benefit of the reduction of dose, i.e., the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, should be maximized.'

The dose limits or any other predetermined dose limits are not considered applicable in intervention (ICRP 1991). The use of dose limits as the basis for deciding on intervention could result in marginal dose savings and could do more harm than good. 'The dose limits are intended to be used in practice to apply to the dose received, not to the dose averted, which defines the implementation of intervention.'

The protection strategy for the population affected by a nuclear or radiological accident is, first of all, to do everything possible to avoid deterministic health effects and thereafter to implement protective actions with the aim of averting doses to the population and to avoid stochastic health effects. The deterministic health effect in radiation protection is defined to mean health risks such as death or vomiting and stochastic effects, e.g., cancer cases. If the projected dose from all pathways approaches the thresholds for serious deterministic effects, protective actions are almost always considered justified. In addition, below the thresholds for such effects the exposure of individuals who are the most at risk could be unacceptable because of a high stochastic risk. Protective actions will in general be justified if the existing annual effective dose is rising towards 100 mSv. This value may be used as a generic reference level for establishing protective actions under nearly any conceivable circumstance (ICRP 2000). The recommended reference level for deterministic health effects and high stochastic risks could be used as a constraint in the justification and optimisation process performed by the decision analysis.

Because of the possibility of deterministic effects and high stochastic risks the protection of individuals and hence the individual dose may be a significant factor in the decision-making process (ICRP 1993). If the protective actions taken are not justified from the viewpoint of the individuals concerned, it should be considered if the collective dose of the exposed group could be reduced by protective actions. It might be that the members of the group could not be known by name like in actions affecting the consumption of food.

The implementation of protective action - including no-action - entails harm and benefit to the population, e.g., monetary costs, social disruption, and psychological or physical health risks. If the benefit of a protective action, which includes the *dose averted*, is greater than its associated harm, the action is justified. Justification requires that the relative importance of attributes in different actions has been judged. This assessment is independent of the decision-making process or aid (ICRP 2000). 'These judgements have to be made irrespective of the decision-aiding technique used. Indeed, they are made implicitly even if a decision-aiding technique is not used. (The technique does not create the need for judgements; rather it makes them explicit!).' A simplified example of justification is a cost-benefit analysis in which the avertable collective dose (manSv) is converted into monetary units by α-value, e.g., 20 000 €/manSv (see e.g. IAEA 1994). If the difference, the avertable dose expressed in monetary units minus the costs of action, is positive, the action is justified.

Justification of protective actions in radiation protection is not independent of other choices made by society and particularly not independent of general protection of health (ICRP 1990; IAEA 1994; OECD/NEA 2002). The resources of a society are finite, and if more resources are allocated to radiation protection, it means that less effort and fewer resources are allocated to other aids of health protection. Respectively, more effort and resources allocated to other types of health protection mean less effort for radiation protection. It is seen to be reasonable that the same amount of effort and resources should be expended to avoid serious illness, above all cancers and premature death caused by radiation or other causes.

The revealed assessment of the resource allocation is not straightforward, although made implicitly in many everyday decisions that involve health risk. The IAEA has discussed extensively the value, in monetary terms, of averting the radiation-related health risk and hence the level of resources to be allocated to reducing the dose (IAEA 1994). As a rough estimation, a sum of 20,000 US$ per manSv saved has been given for typical resource allocation. The range given by ICRP is 3,000 - 100,000 US$ per manSv (ICRP 1993).

If it is possible to choose the form, scale and duration of a protective action or if there are several feasible actions, the best action should be chosen, i.e., the action that maximizes the net benefit. The *optimization* of intervention is achieved by ranking all the feasible actions, e.g., applying decision analysis. The protective action with the highest ranking will produce the maximum benefit. The operational research and radiation protection communities interpret the term optimization a bit differently and the OR does not use the term justification. In the discussion part of this thesis there is a proposal how these terms could be understood when applying decision analysis.

In optimization it is thus assumed that all actions and factors are defined at the beginning of the analysis. In practice, however, it is not possible to define all actions before making some preliminary numerical assessments and running through some rough calculations to gain a feeling for what numbers are important and require refined assessment or even new data collection. Although preferences are associated with numbers in the planning of intervention levels, optimization is not a purely mathematical problem.

Realism is sought in consequence assessment both in nuclear emergency management and in risk management text books, not under- or overestimation (IAEA 1994; Wilson and Shlyakhter 1997). The consequences of an action should be assessed for a well-defined group, e.g., for a municipality or children, which could be met by a feasible action. Below the thresholds for deterministic health effects and high stochastic risk, the dose reduced by an action is assessed with the mean dose in the group to be protected, not on the basis of the maximum individual dose received by a group. If there is a definable subgroup within the defined group, that is more at risk (e.g., forest workers, farmers), the feasible actions for this group should be justified and optimized separately. In addition, if the consequences of an action, which might be a benefit or a disadvantage, concern part of the population not belonging to the defined group, the consequence to the group should also be considered in the decision taken.

The international organisations have also given numerical guidance on intervention levels. The recommendations of the ICRP are based on ‘objective assessment of the health risks associated with exposure levels and on radiological protection attributes’ (ICRP 2000). The Commission has also utilised generic intervention level assessments performed by other international organisations. The advice is expected to serve as an input for the final decision-making process.

The IAEA has provided guidance that could be used as an aid for national authorities in establishing their own intervention levels (IAEA 1994). In order to have a common basis for national decisions the Safety Guide gives generic intervention levels which, prior to accidents, are based on generic accident scenario calculations. Guidance is provided for major protective actions: sheltering, evacuation, relocation, iodine-prophylaxis and food restrictions. Numerical values are derived with cost-benefit analysis.

The expert groups of the World Health Organisation, WHO, has recommended an intervention level of an individual dose of 5 mSv as justified by comparison with variation of natural background radiation (WHO 1988).

The Codex Alimentarius Commission of the Food and Agricultural Organisation, FAO, and WHO have adopted generic intervention exemption levels to control foodstuffs in international trade that have become contaminated with radionuclides in an emergency situation (FAO/WHO 1991). They are intended to be values below which no restrictions are required. The derived intervention exemption levels have been calculated from intervention levels of 5 mSv annual committed effective dose and 50 mSv annual effective thyroid dose (^{131}I), 550 kg of food consumed in one year, all of which is contaminated, taking into account the sensitivity of infants and the food consumption pattern, and dose per unit intake factors for the radionuclides of concern.

The Group of Experts set up under the terms of Article 31 of the Euratom Treaty has recommended that the guidance in the Radiation Protection 87 report should be the basis for setting intervention levels by competent national authorities (CEC 1997). The cost-benefit analysis has been applied to derive recommended ranges of intervention levels. Recommended action levels for foodstuffs are congruent with those of the Codex Alimentarius commission (Council Regulation No. 3954/87).

2.2 The decision-making process

No single agreed structure exits for the emergency management process common to all countries in Europe (Bartzis et. al. 1999, III; Carter and French 2004). There are different persons and organisations that are responsible for decision-making and for implementation of countermeasures at different phases of an accident, and the process vary from country to country. Nonetheless, there are common themes. At the accident site the operator or licensee for the practice is in general responsible for controlling the event. The licensee may also be the first organisation to take the initiative in implementing off-site protective actions close to the site based on emergency plans. In that case a shift of responsibility to the rescue service and/or to the competent authority for implementation and planning of emergency actions will be agreed in the early hours of the incident. In the longer term the decision-making is subject to a country's administrative and legal system.

In minor local accidents the mayor, the head of the local rescue team or the regional fire chief of the municipality concerned leads the operation in domestic accidents. A leading group could be called to assist the regional leader. All relevant local authorities are represented in the group.

At the provincial level the provincial administration board (all pertinent sectors represented) and at the national level, in many countries in Europe, the Ministry of the Interior can issue orders related to rescue operations. The Ministry of the Interior is also generally responsible for the overall co-ordination of actions within the central government, especially in the early phase of an accident or, as in Finland, nuclear accidents abroad with transboundary contamination. The ministry can set up a co-ordination group which is comprised of representatives from all relevant ministries and expert organisations.

The basic principle in nuclear emergency management in central government is that each branch of administration is responsible for preparedness arrangements, emergency responses and information on actions in their own sector of authority. Hence each ministry decides on countermeasures in their sector of authority and presents matters to the Council of State in issues requiring political commitment. The common distribution of responsibilities, which is particularly valid in Finland, is as follows (Sinkko et. al. 2001):

- the Ministry of Health is responsible for the health protection of the population (advice on iodine prophylaxis in contingency plans, psychological aid, social support, medical treatment etc.), and for providing logistics for evacuees;
- the Ministry of Trade is responsible for food and trade restrictions;
- the Ministry of Agriculture is responsible for measures in agriculture, forestry and fisheries and for implementation of the agricultural countermeasures covering primary production, i.e., all foods from field to table;
- the Ministry of Environment is responsible for housing of relocated population and reclamation of contaminated land (waste from decontamination);
- other relevant bodies and ministries in accident situations include the information unit, which co-ordinates information activities. The Ministry of Foreign Affairs is responsible for issuing information to foreign media on national accidents and the Ministry of Transport and Communications is responsible for communications (broadcasting companies), transport etc.

In most countries expert organisation on nuclear and radiation related issues assists all administrative branches. The duties of organisations regarding off-site emergency management are inter alia: to perform radionuclide analyses, to assess the radiation situation, to assess and predict radiation-related health consequences and, as a safety authority, to prepare and give recommendations on countermeasures to other authorities.

Decision-making takes place in groups of various sizes and compositions, ranging from local emergency services through local government to central government bodies. For example, the task of radiation protection and other experts may be to prepare the recommendations or comments which are considered by all relevant parties who have interests in and concerns with protective actions. The formal decision is typically made in the presentation of matters to the President, Governor or maybe, in a less formal way, to the Director General of Rescue Services. For example, later on it may turn out to be necessary that the waste disposal or the coverage of costs requires a new law. A bill is first discussed in a preliminary debate and then sent to the proper committee. After hearing specialists and various parties concerned the committee is to take a statement about the law proposal. It is then sent back to the plenary session for three readings, the last one for passing it. The formal decision is made in the presentation of a bill to the President.

All in all, the power in societal decisions is fragmented, i.e., scattered among many people and many decision-making phases that a single decision-maker cannot exercise much power in a decision. Alho (2004) and Sauri (2002) have observed this fragmentation in the political decision-making process. A precursory activity always has influence on the decision. The sense of power could only be perceived if elected officials, after a reasoned address or report, reconsider their preliminary decision or even change it. Decision-making is often a long process and it is difficult to separate preparatory work and evaluation from each other. It might be difficult to see where and when the actual decision is taken.

In general, a decision has been agreed upon before the formal decision is taken and it is too late to try to affect the decision in the phase of voting or presentation of matters (Sauri 2002). No doubt decisions will be taken outside official meetings, but even in that case, the grounds for a decision should be stated publicly instead of the majority announcing the decision. Sauri (2002) has proposed a way of improving the political culture in which the grounds for a decision or proposals should be announced publicly to be assessed and criticized by all interest groups. The credibility of politics or democracy is always undermined when the grounds are not explained. Susskind and Field (1996) have stressed that in environmental decisions decision-makers and government officials should acknowledge the need for quality information, effective communication and mutually beneficial relationships, not employing techniques such as stonewalling, whitewashing, and blocking and blaming.

Alho (2004) as well as Sauri (2002) has become to the conclusion that the decision-making process should be expanded towards greater openness and transparency. Alho (2004) in studying the exercise the power and the decision-making process in Finland acknowledges the need to broaden opportunities for participation. Participation and rational dialogue are vital for democracy.

An elected official should remain an elected official and not behave as an expert (Sauri 2002; Lackey 1997; Susskind and Field 1996). He or she should control the decision-making process in a way that fixed objectives can be achieved. He or she should speak in such a manner that those who have given the power can understand the issue. Experts should not have the role of an elected official or politician. They make technical calculations and present reports to ensure that elected officials are able to understand the problem and the consequences of decision options. Their role in decision-making process is essential. It has been proven that whoever first writes a reasonable report it will be difficult to change the content of the report during the decision-making process.

2.3 Decision analysis and its application in nuclear emergency management

The ICRP has seen decision analysis as an important practical embodiment of the optimisation concept in radiological protection (ICRP 1989, 2000). The problem could be better clarified if the radiological protection options were properly identified and their performance assessed in terms of risk reduction, costs and other relevant factors. A systematic approach ensures the recognition of the judgements involved.

Operational Research (OR) over the past 40 years has transformed the abstract, mathematical discipline of decision theory into a potentially useful technology known as decision analysis, which may assist key players in handling large and complex problems and the attendant flows of information. Decision theory and its use in decision analysis is a branch of Operational Research, which has links to economics and psychology. Decision analysis is not intended to be used to solve problems automatically. Its purpose is to produce insight and understanding in order to help people to make better choices. It is both an approach and a set of techniques to rank options according to people's preferences. The theory of prescriptive decision analysis is described in detail in the literature (Keeney and Raiffa 1976; Keeney 1992; Winterfeldt and Edwards 1986; French 1988; Goodwin and Wright 1992; Hammond, Keeney and Raiffa 1999). This chapter briefly explains multi-attribute decision analysis and how it could be applied in nuclear emergency planning (Sinkko 1991; Gjörup 1992).

In decision theory it is recognised that people could benefit from the support and guidance of structured decision analysis. Where this is not the case, as e.g. in recurrent, experience-based decisions, it might seem simpler, more efficient and more acceptable to introduce a problem or a complete list of alternatives and their consequences into the decision-making process without recourse to any formal analysis. Nuclear accidents are very rare and their consequences dissimilar. Therefore the decision-making process cannot be based on daily, recurrent experience. An analytical approach could be advantageous in unusual decisions, also helping to focus on pertinent information collection.

Secondly, studies indicate that when left to their own devices people easily create and hold on to many kinds of inconsistent beliefs and preferences (Kahneman and Tversky 1982; Spetzler and Staël von Holstein 1975; Gregory, Lichtenstein and Slovic 1993). This view is supported by research indicating that the correlation between preference rankings derived from holistic judgement and those derived from decision analyses decreases as the number of attributes in the problem increases (Winterfeldt and Edwards 1986). Even in the absence of seriously conflicting objectives, unguided intuitive decision-making is susceptible to many forms of inconsistency. People's preferences may be dictated by the presentation of a problem and not by its underlying structure, which may lead to irrationality.

The essence of decision analysis is to break down complicated decisions into small, manageable pieces that can be dealt with individually and then recombined logically. In this one-step-at-a-time approach many decision problems may be resolved by considering what are the relevant objectives, and alternative actions, what might happen as their consequence and what is the prioritisation among the consequences.

Before any formal or informal analysis is made, it is essential to identify the key players, e.g., the authorities, expert organisations, industry, producers, the public and the formal decision-makers. The decision to be taken and the purpose of the analysis have to be defined as well. The analysis may well serve other purposes rather than lead to prompt decisions. The planning of protective actions in advance is a common example.

Objectives and attributes

Many researchers in the decision theory have proposed that identification of objectives relevant to the decision problem is most important because alternative actions are important only as a means to achieve these objectives (Keeney 1992, 1994). In other words, quoting an old saying, 'if you don't know where you are going, any road would do', fits here. In order to be more useful and understandable, objectives should be measurable. In decision analysis numerical scale are used to evaluate how objectives can be achieved by actions. The related numerical variable is called an attribute.

Objectives and attributes are not always evident, but time and effort is needed to specify them clearly and fully. Incomplete specification will lead to too narrow a focus (Hammond, Keeney and Raiffa 1999). Objective identification could be facilitated by thinking of the pros and cons of potential alternatives. It might also be effective to compare prior attribute definitions in analogous problems.

An attribute hierarchy, also called a value tree, can be useful in defining objectives and attributes (Keeney 1992). The top layer of the tree contains very general and sometimes vague values. The values become more specific the lower one goes down the tree. The building of the objective hierarchy is continued until objectives that are measurable, operational or easy to assess judgementally, are found. Keeney and Raiffa (1976) propose the following criteria for examining the applicability of the attributes: completeness, operationality, decomposability, absence of redundancy and minimum size.

In nuclear emergency management international organisations have listed a generic group or abbreviations of objectives: minimising the radiation dose, physical risks, monetary costs, anxiety and disruption of actions, and maximising the reassurance produced by intervention (ICRP 1991, 2000; IAEA 1994). Certain authors in emergency management community have also written down the definition of fundamental attributes that they have proposed or used in the analysis (French 1992; Hedemann-Jensen et. al. 1996; Morrey and Potter 1994; Atherton and French 1998).

Alternative actions

One essential stage in emergency management and in decision analysis is to identify all feasible alternatives of actions. International organisations have published generic guidance on the primal protective actions considering reduction in dose, especially for the early phase. For planning purposes, protective actions have been listed and categorised into those that restrict people's activities or the use of contaminated food or consumables and into those which prevent radionuclide incorporation in the human environment, food or consumables (ICRP 1991; IAEA 1994).

In planning countermeasures for the event of a nuclear accident generic, protective actions can be developed further by considering the possibility of changing the action's scale, timing and duration. For example, the population group to be protected can be modified. It is useful to iterate between the articulation of attributes and creation of alternatives in order not to end up with too limited set of alternatives. All feasible actions have to be defined - including no action at all - which might be implemented to control a certain exposure pathway. In defining the action, its technical and social feasibility, and national circumstances should be considered; can it be implemented in practice as has been planned?

The aim of radiation protection in nuclear emergency management is to reduce doses by implementing countermeasures. Accidents will cause negative social and psychological impacts. After the Chernobyl accident it was observed that psychological health consequences were the most significant as compared with the economic and radiological ones (Allen et. al. 1996; IAEA 1991). It has been concluded that radiological countermeasures might not withdraw anxiety or stress alone but in addition actions to mitigate social and psychological impacts are needed, for example debriefing where victims by discussions work trough their anxiety (Haukkala and Eränen 1994).

Consequence assessment

Consequences are the values of attributes in various actions, e.g., the assessed doses before and after the actions are taken and the costs of the actions. The measurement of these attributes is easy because we can identify the variables representing them. However, for attributes such as reassurance and anxiety, it will be more difficult to find appropriate statistics or a variable that can be quantified or expressed on a characteristic scale. The technique that can be used to express the preferences over the values of an attribute is grade scales, direct rating of the consequence, which is often used, e.g., in schools and technical magazines.

In direct rating, the most preferred option, for anxiety for instance, is given a value of 100 and the least preferred option the value of zero. The other options are ranked between zero and 100, according to the degree of preference for one option over another in terms of anxiety. The technique seems robust but numbers do not always need to be precise. The availability of relevant information could be more important than its precision.

All in all, rational decision-making requires that the consequences in each action are assessed realistically, without overestimation. Conservatism in assessment may cause overestimation of the benefit of an action, an excess of monetary resources and an increase in unnecessary stress among the population.

There are different consequence assessment tools for nuclear emergency management, for example: ARGOS (http://www.pdc.dk/nucsystems-uk/), COCO-1 (Haywood, Robinson and Heady 1991), OECD/NEA (2000), RODOS (Ehrhardt and Weis 2000) and WSPEEDI (Chino et. al 2000). These softwares are planned to assess, present and predict mainly the radiological consequences of an accident and the monetary costs of actions. However, in the workshops reported here it was not possible to calculate all the consequences needed in the decision-making process. Commercial software can be and were utilised in consequence assessment, for example GIS (Geographic Information Systems) and spreadsheets together with statistical and production information.

Trade-offs

The avertable dose achieved by a countermeasure is probably not of equal importance to its monetary cost. In all decisions - whether explicit or not - the range of attributes has to be balanced, e.g., by assessing the weights on the attributes. They represent the judgement concerning the relative importance of the levels of attributes. For example, how much is society ready to invest to avoid a certain dose? The importance of an attribute not only depends on its conceptual value, such as health, but also on its range of values, such as the number of cancer cases. A thorough assessment of trade-offs is essential for good decision-making but it is not always an easy matter and is prone to mistakes (Keeney 2002).

The trade-off values are subjective, not objective. There are no universal values. The values are related to every specific problem, and in addition, they change according to opinions and are dependent on resources of a society. There are methods and studies which make it possible to estimate trade-off values and shed more light and understanding on the values, for example, studies on willingness to pay and the costs of life-saving interventions (Bengsson and Moberg 1993; Katona et. al. 2003; Ramsberg and Sjöberg 1997, Tengs et. al. 1995). They have reported variations over 11 orders of magnitude in values with the median of 20,000 - 40,000 US$ per statistical life saved per year. Tengs (1995) has concluded that more lives could have been saved by shifting resources between life-saving interventions.

However, methods such as willingness to pay studies and contingent valuation, that are carried out to prevent harm, have been criticised. The problem with contingent valuation techniques is that 'they capture attitudinal intentions rather than behaviour, important information is omitted from questionnaires and their results are susceptible to influence from cognitive and contextual biases' (Gregory, Lichtenstein and Slovic 1993). The results of willingness to pay studies are not any more useful because case studies are usually poorly structured and do not indicate the multidimensional values behind decisions. Values are multidimensional and people have strong feelings and beliefs about these values, which typically are not numerically quantified and are not expressed in monetary terms. Careful structuring of the problem is necessary to identify the underlying multidimensional values, attitudes to risk and trade-offs related to the problem. These are created during the elicitation process in decision analysis. Therefore, it does not seem reasonable to assess trade-off values using problem independent studies. Indeed, a proposal has been made to adopt the multi-attribute value/utility theory in contingent valuation studies (Gregory, Lichtenstein and Slovic 1993).

Uncertainties

Value models, such as MAVT and cost-benefit analysis (CBA) are used in the planning of countermeasures in the event of a nuclear accident (IAEA 1994; Sinkko 1991). They are inappropriate if major uncertainties are connected with the decision, as in nuclear emergency management. In many protective actions the consequences of alternatives cannot be predicted with certainty. For example, depending on the course of the accident, it is possible that much higher or lower doses than estimated will result, or it is not known how successful the action will be. Even if the fallout pattern has been measured, the dose distribution could be substantial. The consequence assessment of other attributes is equally uncertain. Utility analysis (MAUT) is designed to allow both uncertainties and risk to be taken into account. For example, if felt appropriate, it is possible to use the individual dose instead of the collective dose in the calculations by considering the individual dose distribution. There is also software which makes it possible to incorporate distributions into the analysis (Smith 2002). Incorporation of uncertainties into an analysis, however, requires an understanding of probabilities and - if done in an orthodox way - a series of potentially difficult questions for decision-makers.

Should any uncertainty exist, an important issue is to distinguish a good - analytically premeditated - decision from a desired consequence. Because the outcome is uncertain a good decision does not guarantee the realisation of the most desired consequence. A decision cannot be qualified based on its true consequence (Hammond, Keeney and Raiffa 1999).

Group decisions and facilitated workshops

Decision analysis is based on the preference model of a single decision-maker. However, in reality, a decision is rarely taken by a single person, but by a group of key players. It is more complex to develop a mathematical model for rational group decisions than a mathematical preference model for an individual decision-maker (see, for example, French 1988 for more extensive theoretical discussion). Indeed, the well-known Arrow's theorem suggests that for each possible arrangement there is a set of individual preferences such that the group preference constructed from individual preferences breaks at least one of the axioms attached to group behaviour (Arrow 1963, 1984). Nevertheless, it is possible to support key players in a manner that can be characterised as useful and informative. A fair and just solution to a group decision problem can be found only if each member of the group behaves rationally and equitably.

In group decisions as well as in individual decisions decision analysis assists key players towards a greater understanding of the problem and the preferences of the other members of the group. Furthermore, the analysis guides the discussion in a positive and constructive way; there are fewer possibilities to jump from one issue to another without direction or progress in the discussion (French 1988; Phillips and Phillips 1993).

A facilitated workshop (also called a decision conferencing) is an interactive approach to group decision making in order to generate a shared understanding of the problem and to produce a commitment to action. A facilitated workshop combines decision theory, group processes and information technology over an intensive, up to two- or three-day session attended by key players with different fields of expertise. The original arrangement is that a small group of key players is seated in a semicircle to discuss the problem through a facilitator who aids the group's discussion and sharing of knowledge. In the background an analyst, using decision-aiding technology, models the group's views (Phillips and Phillips 1993).

Phillips argued that decision conferencing produces conditions for creative and effective decision-making. Participants are not on home ground (Phillips 1984). Usually sessions take place in hotels, or in an especially designed room on the facilitator's premises. The group is carefully composed of problem owners representing all perspectives of the issue to be resolved. It is recommended that the facilitator should be a professional and neutral outsider (Phillips 1984; Susskind and Field 1996).

Decision analysis techniques

The decision analysis approach in this work is based on multiattribute value (MAVT) and - utility (MAUT) theories (Keeney and Raiffa 1976; French 1988). The selections were made because these theories are well developed and tested for many years and have an axiomatic foundation. These methods are very applicable also in facilitated workshops where the purpose is to guide the thinking of key players, help them to make consistent judgements and to choose rationally. There are other multiattribute evaluation methods such as the analytic hierarchy process, fuzzy decision analysis and multiattribute outranking analysis. All these theories have proponents and opponents (see e.g. French 1988).

The cost benefit analysis (CBA) has also applied in planning of protective actions in advance (IAEA 1994; Gjörup et. al 1992). The costs benefit analysis has its basis in economic theory. Typically analysis is prepared to provide decision-makers with information and do not require decision-makers to express value judgements (French 1988). Therefore, the CBA method is not very applicable in the workshops where the judgements are performed with the key players. The apparent difference is also that in the MAVT the values of attributes are converted into common units, whereas in the CBA values are converted into monetary terms. All effects are translated to financial values regardless of how intangible they might be. This poses problems when human health is the main issue. In the workshops some participants pointed that money is not important in the decision on protective actions.

The quality of any decision analysis will depend on how digestible the problem is structured and how careful consequences of alternatives have been pondered. The decision problems, which are deliberated and judged carefully, the outcome of a decision analysis from all evaluation method could well be the same. The prerequisite is that all pertinent attributes, action alternatives and trade-offs are judged equally. This is not likely to be true if risk attitude of a decision-maker is a major issue. In that case the MAUT analysis offers a reliable method to manage the problem.

3 Objectives of the study

The overall objective of this study is to develop methods and techniques to evaluate systematically protective action strategies in such a way that all key players' concerns and issues could be considered openly and taken equally into account in the decision taken (Hämäläinen et al. 1998, Hämäläinen et al. 2000, VI; Ammann et al. 2001, VII). An important outcome of the work is the creation of preconditions for participatory decision-making in the event of a nuclear accident (Sinkko et. al. 2004, I). The specific objectives are:

- to plan analytically countermeasures with all pertinent key players. International organisations have also recommended analysis of protective actions on a national basis;
- to define the generic attributes that have to be considered when setting intervention levels. Only a few analyses exist where all important attributes and their relative importance for the decision taken have been considered and discussed explicitly (Aumonier and French 1992; French et. al. 1996; International Chernobyl Project 1991; Sinkko 1991; Zeevaert et. al. 2001);
- to study how the area, timing and duration of an action should be defined in order to maximise the reduction in radiation detriment and at the same time to minimise the detriment associated with the intervention;
- to study how single protective actions can be bundled into overall strategies in the affected area. Although protective actions could be optimised independently from each other, in practice the actions are dependent or sequential, e.g., agricultural countermeasures are dependent on evacuation and relocation. The dependence or sequence might influence on value tree or value trade-offs;
- to study and develop the applicability of decision support systems for different situations. In the early hours of an accident there is hardly time to model the decision to be taken; rather the decision has to be based on intervention levels studied and considered beforehand and on guidance given by a decision support system (DSS). In the later phase of an accident, however, there is time and need to perform detailed and more specific analyses;
- to study how uncertainties could be incorporated into nuclear emergency management. In the early hours of an accident uncertainties are dominant, concealing factors which might become apparent in the later hours of the accident. There are also large variations, e.g., in the health consequences for the population.

4 Materials and methods

In this study a series of facilitated workshops have been organised in the Nordic countries to analyse protective actions and to develop methods for key player participation in the event of a nuclear accident. The workshops were jointly arranged by the RISØ National Laboratory, the STUK - Radiation and Nuclear Safety Authority and the University of Leeds (UoL), in Denmark in 1992, and by STUK, RISØ, NRPA (the Norwegian Radiation Protection Authority), SSI (the Swedish Radiation Protection Institute) and UoL in Sweden in 1995, and by STUK and the Helsinki University of Technology in Finland in 1997, 1998, 1999 and 2001. STUK was responsible for the co-ordination, development of the accident scenarios, consequence assessments and for contacts with the key players. The University of Leeds and Helsinki University of Technology were responsible for the decision modelling, the analysis approaches and the implementation of the decision support software as well as for the facilitation of the workshops.

The Nordic co-operation organisation (NKS Nordic Nuclear Safety Research) funded the first two workshops held in Denmark and Sweden (French et. al. 1993, IV and 1996). The members of these workshops were local government officials, emergency planners and members of the radiation protection community from all the Nordic countries. The two subsequent workshops and decision analysis interview were conducted within the fourth Framework Programme of the EU (Hämäläinen et. al., 1998, and 2000, VI). The last workshop was funded by Finnish sources consisting of the Foodstuffs Industry Pool, the National Emergency Supply Agency and Valio Ltd (Ammann et. al. 2001, VII).

Within the NKS the KAN-2-project was performed in 1994, the purpose of which was to provide basic data and methodology to improve the planning of protective actions in the event of nuclear accidents. Special attention was paid to the tail-end topics of the clean-up process; management and disposal of radioactive waste. As part of this project decision analysis was performed in which recovery operations to clean up a forest environment were analysed and discussed to determine appropriate intervention levels in a hypothetical nuclear accident to protect the public, workers and the environment (Sinkko et. al. 1994, V).

The work is based on case studies where the key players were invited to consider a scenario of a hypothetical but realistic nuclear accident. It was assumed that a core-damage and containment leak accident had occurred at a nuclear power plant, leading to contamination of the environment. To increase realisticness, in most cases the accident sequence was taken from probabilistic reactor safety studies (PSA) performed by the NPP and STUK safety experts. It was also considered important that the current emergency management process of the administration was followed closely and that all relevant key players were represented at the meetings. Contacts were made and preparatory meetings held prior to workshops, as would be the case in a real situation.

Several protective actions and the bundle of actions, i.e. strategies, were selected to be considered in the workshops. The workshop held in Denmark considered countermeasures in a situation where early phase protective actions had been taken and decisions on later phase protective actions were to be considered (French et al. 1993, IV). The main issue was to consider whether to relocate people in certain areas. The theme in the second Nordic workshops was the decision on clean-up actions in inhabited areas (French et. al., 1996). The first Finnish workshops focused on early phase countermeasures, i.e. iodine tablets, sheltering and evacuation (Hämäläinen et. al. 1998). The attributes and their definition related to the decision of early phase protective actions were studied in depth. The incorporation of uncertainty into emergency management was studied in these workshops and in the interview analysis (Hämäläinen et. al. 2000, VI). The task of the last workshop was to plan countermeasures to reduce the dose received from consumption of dairy products contaminated by radionuclides (Ammann et. al. 2001, VII).

The simulation of the radiological situation and the generation of countermeasure strategies, together with the assessment of their consequences, were done in advance. The participants were given an information package comprising thematic maps of the radiological situation showing an animation of the dispersion, dose values and assessments of health and economic consequences. The information was also provided in the form of consequence tables. The possible precautionary actions taken to protect the population were mentioned. A list of predefined attributes, the parties involved in decision-making and their duties were attached. All in all, the package was designed to contain all the relevant information necessary for the participants to understand the accident situation and to be able to take an informed decision on the countermeasures to be recommended to formal decision-makers.

At the beginning of the workshops the list of attributes was presented and introduced for discussion. The participants were urged to go through, revise, remove, add and redefine any attribute they wished. During the whole discussion the attribute hierarchy was displayed and suggested changes were incorporated on the fly. Eventually the group agreed on the final set of attributes. The 'hard' attributes, i.e. the number of cancer cases and costs were calculated in advance, but the 'soft' attributes such as social disruption and anxiety, were directly rated during the workshops. A decision model was constructed and value or utility analyses were performed, including sensitivity analysis with commercially available software. At the end of the workshops the results were discussed.

5 Results and discussion

5.1 Emergency planning

The workshops aimed to elicit justified protective actions or their combination, i.e. strategies of which the scale, timing and duration were optimised in the given situation (optimisation in the sense of radiation protection). Decision analysis has been developed to evaluate and identify the best strategy, i.e. to rank strategies but the term justification is not used in the OR. The justification of actions is conceptually clear but not easily measured. The ranking of countermeasures embodies many value judgements such as the assessment the importance of attributes. If all possible alternatives are considered, the best ranked option should also be justified. Thus the justification is implicitly included in the decision analysis. In traditional vocabulary, the best ranked protective action is justified and optimised. (Sinkko et. al. 2004, I).

International organisations define justification slightly differently. Attributes are most often seen to have either a positive or negative quality; more is better than less (positive) or less is better than more (negative). In nuclear emergency management, avertable dose and reassurance for instance are positive, while anxiety and monetary costs are negative. For the justification process the quality of attributes should be agreed and the relative importance of attributes, i.e. their weights, be judged. Relevant value for weighting is the difference between the value of an attribute in the action under consideration and in the worst action, not its conceptual value. An action which aggregated sum of weighted values is positive is justified. A simplified example of justification is given in figure 1.

The judgement of the relative importance of attributes is not a task of the radiation protection community. It contains the judgement, how much society should invest its resources to health care and, particularly in this context, to avoid radiation risk. The overall justification and optimisation might show that resources are more needed for other health care purposes, and protective actions are not justified. The radiation protection community has a responsibility to be aware of the amount of resources it would be appropriate to allocate to reduce radiation risk, to be comparable to other reductions in the health risk and to hand this information on to formal decision-makers along with transparent recommendation.

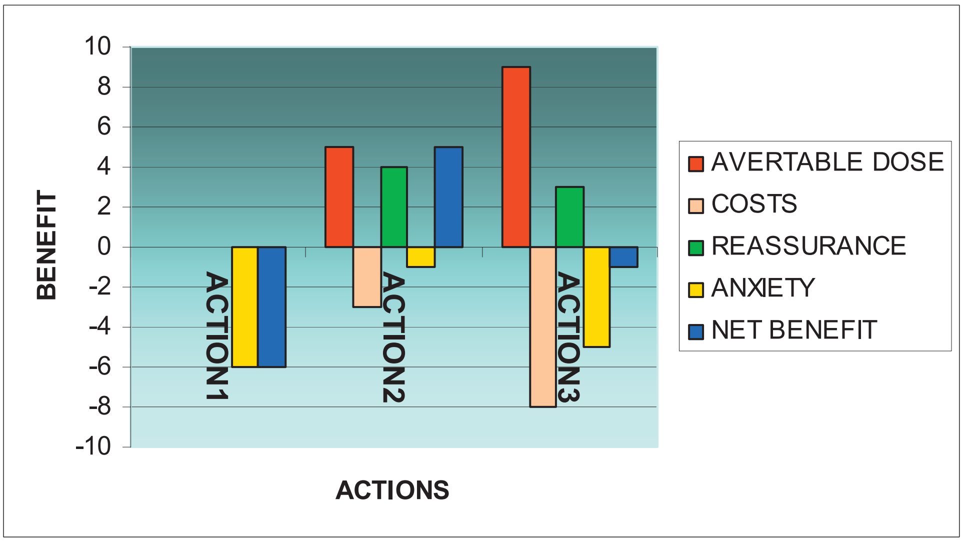

Figure 1. Principled justification of three actions considering four attributes. The height of the bars illustrates their relative importance in the decision. The bar on the far right (blue bar) is the aggregated, summed up net benefit in each action. In action one avertable dose, costs and reassurance have been considered with a value of zero. Action two is justified.

The relative importance of attributes is subjective and no universal values exist (Sinkko et. al. 1994, V). The values are related to the unique problem and they change according to opinions and resources. As a consequence, intervention levels based on generic planning or case studies are very rough and their applicability to a new situation should be verified.

There should be a clear understanding of the countermeasures and factors affecting the decisions. The timing, duration and target area of actions, and the group aimed to be protected by the actions could be quite easily assessed and should be clearly defined. The objectives and attributes are not self-evident. In workshops much time was spent on defining factors and wording used in value elicitation. Especially intangible attributes such as anxiety, reassurance can commonly be interpreted differently. It seems to be beneficial to define the attributes in advance in order to save time and to guarantee that all key players understand their meaning in the same way. The definition of attributes in advance is contrary to the standard way of using decision analysis and possibly leads to such biases as availability or anchoring. Value assessments could thus be based on information that is visualised and useful modifications in attributes are not made. For example, if anxiety is available in the list it might be given too much weight or technical feasibility omitted if not mentioned. However, nuclear accidents are rare and key players are not very familiar with the radiological issues or related terminology. It was found that in order to harmonise the discussion it is practical and efficient to start with a predefined, preliminary model of attributes (Sinkko et. al. 2004, I). The participants were asked to fill in questionnaire after the workshops in order to find out their opinions on the decision analysis and the workshop method. The questionnaire confirmed that the participants were rather satisfied with the predefined attributes and ensured that all relevant factors were included in the model (Ammann et. al. 2001, VII).

The following set of generic attributes has been deliberated upon with the insight gained during this work (Ammann et. al. 2001, VII; French et. al. 1993, IV; French et. al. 1996; Hämäläinen et. al. 1998; Hämäläinen et al. 2000, VI; Sinkko et. al. 1994, V). Although attributes are elicited in different case studies covering early as well later phase actions such as evacuation, milk pathway, clean-up and forest, attribute validity in a new situation should be verified:

Collective dose to the public. The standard assumption within the radiation protection community is that exposure to radiation increases the risk of cancer, however small the exposure. If the individual risk is very small, stochastic health effects are still expected when large population groups are exposed. This attribute could be measured as the projected collective dose to the public (manSv). It could also be converted into the *expected number of fatal cancer cases or number of cancer incidents* to be more comprehensible for persons outside the radiation protection community. A risk factor or nominal probability coefficient for stochastic effects of 5 x 10^{-2} per Sv could be used to assess the probability for fatal cancers (IRCP 1991). Excepting thyroid cancers, it could be assumed that roughly half of the cancer cases can be cured, i.e. there are twice as many incidents as fatal cases. A figure to be calculated with a DSS as an input in the decision-making process could be estimations of the additional number of cancer cases or collective doses with and without countermeasure options (i.e. avertable doses).

Individual dose to the public. Some members of the public might be subject to a relatively high stochastic risk or be at risk of incurring deterministic effects (the critical group could be defined as in Basic Safety Standards, IAEA 1996). Their risk has to be considered individually and can be measured by the individual dose. It is worth noting that there is a correlation between collective and individual dose attributes if both are used in a decision analysis (Sinkko et. al. 1994, V). This attribute could be measured with *effective external dose and / or organ dose* in normal living conditions and when an action is taken integrated over the action period (e.g. sheltering or evacuation time, units in mSv).

Number of thyroid cancers in children. Thyroid cancer deserved special consideration because it is predominantly children that are affected. In addition, thyroid cancer, which has a latency time of only a few years, is rare and is easily seen in statistics. The better response to treatment of thyroid cancer is another aspect that needs expression, i.e. roughly 10% of thyroid cancers prove fatal, whereas on average an assumed 50% of all other types of cancer cause premature death. The risk factor to calculate the number of fatal thyroid cancer cases is 0.08 x 10^{-2} per Gy (ICRP 1991). A figure to be calculated: *thyroid dose in children* from intake of radioiodine in normal living conditions and when an action is taken (mGy).

Number of thyroid cancers in adults. A breakdown of the number of *thyroid cancer cases* into those expected in children and those in an *adult* population might be useful. A similar breakdown for other cancer types might also be helpful. A figure to be calculated: *thyroid dose in adults* from intake of radioiodine in normal living conditions and when an action is taken (mGy).

Dose to the workers. Projected individual dose received by the workers carrying out protective actions generally outdoors (mSv). If large numbers of emergency service employees are exposed to radiation (e.g., during clean-up actions) the increased number of expected fatal cancer cases in the group or their *collective dose* could also be used as an attribute (manSv). Dose limits to workers have to be observed. A figure to be calculated: *effective external, organ- and/or skin dose* during work hours (mSv).

Statistical non-radiation fatalities. The collective physical risk is largely dependent on the number of people affected by protective actions and it may not be much higher than the risk associated with normal human activities. For example, it has been concluded that the health risk introduced by stable iodine prophylaxis, prolonged sheltering or evacuation is very low (Aumonier and Morrey 1990). Since there is only sparse information on accidents caused by other countermeasures, the general statistics could be used as an initial approximation for other countermeasures, e.g. for the risk of road accidents during evacuation. This attribute could be measured as the *number of fatalities or reduced life expectancy* in the alternatives considered.

Individual non-radiation fatalities. In some accident scenarios there might be a population group that is at higher risk of suffering death in the course of taking countermeasures. It might be important to consider individual risks, for example, when evacuating the young, the elderly or patients in very bad weather conditions, since evacuation under such circumstances might endanger their lives. This attribute could be measured as the *number of fatalities or reduced life expectancy*.

Social disruption. An accident and how it is reacted to, poses a severe threat to the industry and primary production. Firstly, there would be loss of income, for example, due to direct restrictions in selling products that exceed the maximum permitted concentration or contamination levels. But then consumers may also react unpredictably and reject all products that are somehow related to the affected area. Exports may suffer from a total loss of confidence in a country's products. All this amounts to a threat to posed to producers and employees in industry, and the subsequent loss of their livelihood can cause social disruptions. Evacuation or relocation may break down the social network, which cause disruptions. *Direct rating* of alternatives.

Anxiety of the population. Anxiety could be defined to be a combination of fear and the emotions of sadness, guilt, anger and shame. (Izard 1977). The majority of the persons living in the contaminated area may show varying degrees of psychological reactions in response to an accident (e.g. miscarriage of unborn children). But stress may also be introduced by the protective actions. The severity of an accident is likely to be perceived through the protective measures taken, i.e. the more extensive these are, the more severe the accident must be and consequently the higher the health risk. *Direct rating* of alternatives.

Reassurance of the population. In the long run, appropriate and reasonable extensive actions may reassure the people living in the affected area. Especially measures that people can implement themselves are most effective in reducing stress. *Direct rating* of alternatives.

Anxiety of the workers. Emergency actions will cause stress among workers who are implementing them. *Direct rating* of alternatives.

Environmental issues. Protective actions may remedy or insult the living conditions of flora and fauna. Environmental issues may be related to specific countermeasures, for example, waste management in clean-up actions may cause environmental damages whereas clean-up itself may improve the situation. *Direct rating* or another numerical value depending on the case.

Social feasibility. Some actions may not be perceived as adequate (slightly contaminated foodstuffs), restrictive or even not accepted (relocation). People are not ready to follow recommendations which are against their wishes or attitudes. *Direct rating* of alternatives.

Technical feasibility. Technical feasibility is understood in relation to defined quality or quantity. This attribute is in many cases a constraint preventing the implementation of an action. Large cities can hardly be evacuated and sheltering, too is difficult. In some cases actions may differ in their feasibility, e.g., sheltering is more feasible than evacuation in bad weather conditions. *Direct rating* or another numerical value depending on the case.

Flexibility of strategies. There may be substantial uncertainties in consequence assessment and therefore it should be possible to modify strategies as more information is collected. *Direct rating* of alternatives.

Monetary Costs. This attribute might contain the direct and indirect costs of protective actions. Cancer treatment costs, associated loss of GDP, and other costs that are proportional to the number of cancers should not be included in this attribute in order to avoid double counting. *Monetary unit.*

Risk studies have suggested that perceived risk and related attributes (e.g. confidence) might be major factors in the final decision-making in policy problems (National Research Council 1989). Confidence in authorities is often thought to be of crucial importance for risk perception in an expert organisation. Recent studies, however, have shown only a weak relationship between confidence and risk perception. A much stronger correlation has been found between risk perception and unknown effects (Sjöberg 2001). Contrary to the opinion of experts, politicians and members of the public believe that there are many unknown effects that are not yet understood but still affect their risk perception and consequently their behaviour, for instance, as consumers. These types of attributes were not considered in the workshops. Expert organisations should, however, be aware of the reasons why perceived risk and related attributes might be added in final policy decisions. Attributes, such as 'confidence' and 'unknown effects', which would increase the intervention level, should thus be kept in mind but not considered on the expert level while preparing recommendations.

Political objectives and attributes might be part of decision-making on protective actions but they need to be clearly defined. Politics is by definition activity directed to social matters, a programme or procedure and it could not be as such a measurable attribute. Politicians and authorities write and maintain political programmes and the definition and incorporation of these attributes in the decision-making process is their natural task.

One objective of this study has been to analyse protective actions on a national basis and derive national interventions levels. Therefore it was stressed that the intervention levels recommended by international organisations should be forgotten for a while in the workshops. However, some intervention levels, e.g. radionuclide concentrations in foodstuffs should have been considered in the workshops because of their mandatory status as EU regulation. It cannot be deducted from the result of their overall influence on the intervention levels derived in this work. International recommendations are important reference levels and will be compared in a real situation.

Although the number of actions considered in the workshops do not cover all possible actions some, remarks on intervention levels could be made. The calculated intervention levels are given in Table I. More countermeasures were considered than is given in the table, but in the method applied here the intervention level could be recalculated only for the best ranked action. In addition, taking into account the time constraints in the workshops it was impossible to undertake a systematic analysis to derive optimal intervention levels for the accident scenario. More flexible tools to modify protective actions and assess their consequences would have been needed, too.

Table I. Intervention levels in terms of averted dose derived from results of workshops compared with the levels recommended by ICRP, IAEA and EU. The IAEA and EU levels for milk are generic action levels and maximum permitted levels, respectively.

	Derived from workshops	**ICRP**	**IAEA**	**EU**
Iodine prophylaxis	10 - 100 mGy 0.7 - 1.4 mGy [1, 6)]	50 - 500 mSv	100 mGy	some tens to a few hundreds mGy
Sheltering	0.5 - 5mSv/24h 1 - 2 mSv/12h [1, 6)]	5 - 50 mSv/day	10 mSv/ < 2 days	a few to few tens mSv
Evacuation	10 mSv/month [2)] 5 - 50 mSv [3)]	50 - 500 mSv/ < 1 week	50 mSv/ < 1 week	a few tens to a few hundreds mSv
Milk ^{131}**I**	50 Bq/kg [5, 6)]	10 mSv/ 1 year [7)] 1000 - 10 000 Bq/kg	100 Bq/kg	500 Bq/kg
Milk ^{137}**Cs**	100 Bq/kg [5, 6)]	10 mSv/ 1 year [7)] 1000 - 10 000 Bq/kg	1000 Bq/kg	1000 Bq/kg

[1)] Early release phase with uncertainties. Assessment is based on certainty equivalent value
[2)] Individual dose in the first month. Evacuation was planned for six months and avertable dose estimation was 22 mSv.
[3] Evacuation time was not considered
[5] Provision of uncontaminated fodder or upgrading milk to cheese or butter to protect the milk pathway.
[6)] Action level.
[7)] Restriction to a single foodstuff.

The analysis of the milk pathway nevertheless suggests that countermeasures at concentration levels a decade below internationally recommended intervention levels can be justified in certain accident scenarios (Ammann et al. 2001, VII). The banning and disposal of milk was never considered optimal. Banning would create an enormous disposal problem and the legal aspects of such a measure are unclear. No emergency plans exist for the dumping of large amounts of contaminated substances such as milk or milk powder, processing water or grass. Milk is produced daily and is difficult to store; and therefore any alarming contamination of milk would consequently call for an almost immediate decision. For these reasons it was suspected that the disposal of milk was not a feasible option at all.

Understanding uncertainties and determining the risk marginal is problematic. During the pre- and release phases of an accident the released amount of radionuclides is the main source of uncertainty. The range could be several orders of magnitude. The consequence tables of 5, 50 and 95 per cent release fractiles were calculated and shown to the participants in the workshops. Many participants were not familiar with decision analysis and some did not feel comfortable with modelling tools and had problems in understanding the procedures how uncertainties were incorporated in the analysis. It is likely that the 95% fractile had a strong influence on their decision and as a consequence the action levels in Table I are lower than might be expected from the normative utility analysis. In the workshops there was not enough time to explain in detail the utility analysis. A way forward to incorporate uncertainties in nuclear emergency management is to perform the utility analysis in advance and scrutinise it in the workshop.

Many times in the workshops it was pointed out that the way the public is informed about the accident and the countermeasures taken are crucial (French et. al. 1993 IV; Hämäläinen et. al. 1998). People's reactions depend on what information they are given and how they interpret the situation. In risk communication the goal cannot only be to make the messages more effective by improving the understandability and the credibility of those who disseminate information (National Research Council 1989). Such an approach might serve their interests but could degrade the overall quality. Good risk communication helps the recipients to solve their problems at the same time. People need timely delivered clear, understandable and unambiguous information in order to cope with situation (Eränen 1997). Decision analysis will help to reveal this information because its focus is in decision-making. It is important not to conceal pertinent information and knowledge that is needed for decision-making in an emergency (Susskind and Field 1996). It is equally important to tell what is known and what is not known and not to speculate.

5.2 Decision analysis

It is important to learn where in the decision-making process decision support in the form of a workshop would be appropriate. Facilitated workshops do not fit comfortably in the representative decision-making process as a forum for making final decisions concerning many key players (French et. al. 1996). Preparation of a decision is often divided into so many phases carried out by so many people that a single decision-making point cannot be identified. In a workshop a single decision-making point is presupposed. Commonly, elected officials and authorities do not participate in consequence assessment or in the preparation or evaluation of a decision; instead they expect prepared advice from experts (Apostolakis and Pickett 1998, Lowry, Adler and Milner 1997; Sauri 2002). After the Nordic workshop held in 1995, the Lord Mayor of Helsinki and the former Minister stressed that higher level officials desire advice as to both alternative actions and the grounds for a decision (Siitonen 1995).

Experience gained from this work supports the view that facilitated workshops fit well into the planning phase in a decision-making process where the key players with expertise in different areas evaluate the options to be given for final debate before the formal decision is taken (cf. Fig 2). The decision-maker's control of optimisation is ideal. In practice she or he would rather wait, avoid the commitment to the outcome and take distance if necessary (Renn et. al 1995). A common problem with all participatory methods is that there is no interaction between the key players' group and politicians or higher level authorities. The input could be improved by the analytical process, and by a fair and competent stakeholder group, but it could not be thought that careful input would overcome political forces.

Time is limited with the key players, too and a two-day facilitated workshop as proposed by researchers (see, e.g. Phillips 1993, French 1988) does not fit always comfortably with the decision-making process in practice. Spontaneous decision conferencing could solve the time constraints (Hämäläinen et. al. 1995). This study supports the view that if the information is in the proper form the workshop could be carried out in a shorter time. Prior to the optimisation process, preparatory meetings and discussion with different key players might be needed to collect information and sound out views on the problem. It is also seen to be important to establish face-to-face dialogue with the victims of an accident (Dubreuil 1999; Susskind and field 1996).

Decision on protective actions could affect large sections of the population and have important social and psychological impacts. The decisions taken need to be explained and justified and will be subject to scrutiny for a long time afterwards (Hämäläinen et. al. 1998 and 2000, II). Decision analysis could assist in this process. During the analysis, protective actions are defined, and the consequences and their importance are assessed, which would provide a way of explaining the actions taken and actions omitted. The majority of participants felt that formal analysis provides transparent decision-making that can be utilised for this purpose. The primary benefit of the decision analysis could be improved understanding and communication (Kadvany 1995).

The participants were asked to fill in questionnaire after the workshops in order to find out their opinions on the decision analysis and the workshop method. All the participants considered the workshops useful, and most of them also thought that a similar approach could be valuable for training and exercises. The attitude towards its application in the event of a real emergency was slightly more reserved, but in general still positive. The suitability in an early phase of an accident was rated the lowest.

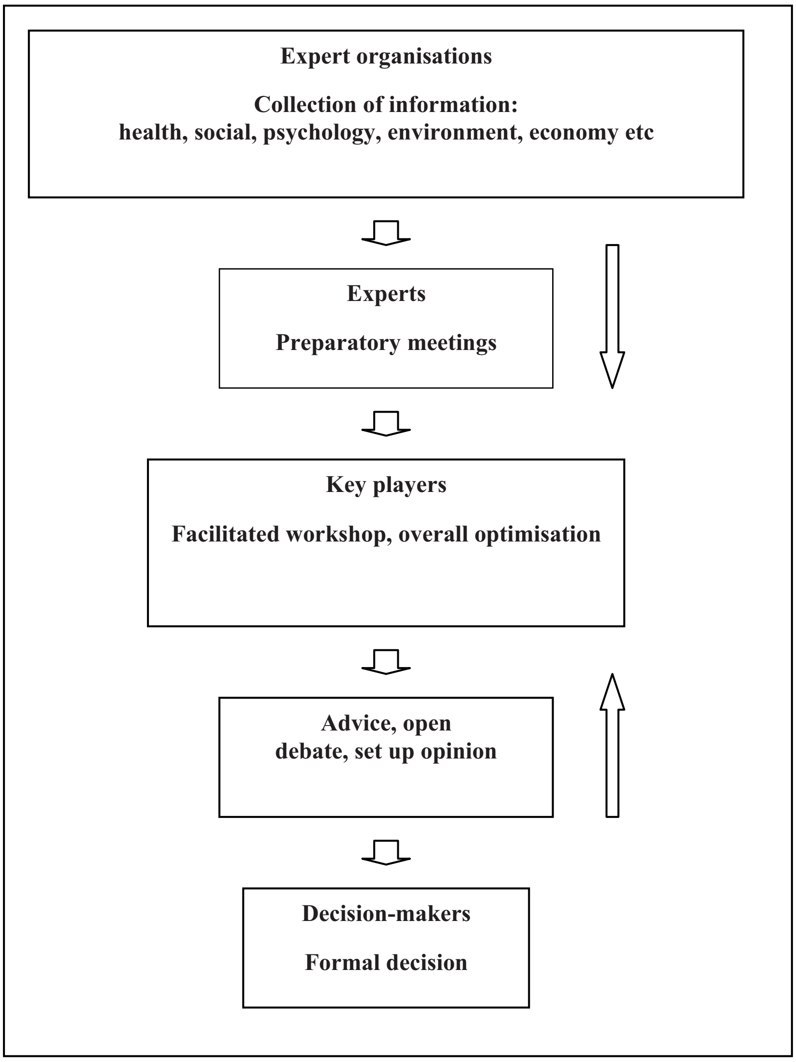

Figure 2. A schematic view of an ideal committee type decision-making process applicable in representative decision-making process.

The impression is that the participants were not very familiar with this type of analytical approach and opinions were divided for and against. Some found that the benefits were obvious but some did not feel comfortable with the modelling tools and had problems in understanding of the procedures such as weighting of attribute scales and utility analysis. The definition of the attributes and the countermeasures, and decision table were easily adopted. One reason why some were reluctant to decision analysis might be that they were expecting a recurrent decision-making process where experience is available. This attitude not to seek judgemental support has been observed also in other workshops (Bartzis et. al. 1999, III). This kind of method had been seldom applied in radiation protection and before the workshop there was no training for participants. Only a few hours were spent on the issues and consequently there was not enough time to explain in detail all the decision analytical methods used during the workshops. In future new applications of the approach to appropriate problems are likely to increase acceptance and understanding of the techniques. The applicability of decision analysis could also be improved by avoiding the excessive verification of theoretical correctness, which is often difficult to understand by participants. The procedural correctness of the decision analysis is left to be taken care of by a facilitator.

The most difficult part of the analysis was the elicitation of the risk attitudes as required in theory when facing uncertainties (Hämäläinen et. al. 2000, VI; Bartzis et. al. 1999, III). The lottery questions were asked in order to establish the form of the utility functions. It was clear that most participants had problems perceiving the idea of utility function. Using lotteries seemed too abstract and the questions too difficult for the participants in order to be able to give meaningful answers. The outline of the analysis could be prepared in preceding meetings and given in the information package. This could lead to an anchoring bias, but if a technique how to deal with uncertainties is not understood the result of the analysis might prove useless. In practice, a good approximation to a full utility analysis is to use multi-attribute values evaluated at the expectations of the attributes (French 1996, Stewart 1995). Although subjective the expectations values could be better understood that hypothetical lotteries.

The choice of action was strongly influenced by trade-offs. Because of its importance the method needs further improvements. *Swing weighting* is recommended as an assessment method for the trade-offs (Von Winterfeldt and Edwards 1986). The decision-maker is asked to compare a pair of hypothetical actions which differ only in their values along two attribute scales. In the workshops, however, it was found that hypothetical options needed clarification and did not suit well to the problem at hand. It would be more logical to ask directly how much more important an attribute range is compared to another's range of values, as was done in the first workshop in Denmark (French et. al. 1993, IV). The *Even swap* method could also be applied (Hämäläinen et. al. 2003). This is a form of bartering where the values of attributes are changed so that one attribute will have the same value in all alternatives (Hammond et al, 1999). If all alternatives are rated equally for a given attribute, it could be ignored. The method could be applied iteratively and eliminate attributes until a clear choice emerges.

In a workshop we observed a high trade-off of 10 million € per averted cancer death. This amount of expenditure is clearly outside the range recommended by international organisations, i.e. 0.05 - 1.8 million € per averted cancer death (3000 - 100,000 US$ per manSv, see e.g. ICRP 1993; IAEA 1994). Another viewpoint has been presented by Keeney (1994). All costs would eventually be passed on to the general public. Environmental regulations may include lower wages, higher taxes and, ultimately, less income available for health care, nutrients etc. According to the estimation of Keeney (1994) based on life expectancy and GNP in different countries, roughly 10 million € paid for regulation will cause one statistical fatality. There was not much discussion on this specific trade-off, so it cannot be stated whether the participants would truly be willing to suggest this kind of an investment (Hämäläinen et. al 1998).

6 Conclusions

The objective of this work was to plan systematically countermeasures in advance and to develop methods to include objectives of all key players in the decision. New theoretical methods were utilised and demands for open group decision-making were considered and tested in the workshops. The developed method applied employs a group process where responsibility is placed on the participants to assimilate information and to provide judgements. It has a clear structure based on the theory of the Decision Analysis which provides reasoning and learning framework that intertwines the beliefs, preferences and value judgements of the participants and achieves a transparent ranking of the strategies available. Decision analysis had a major role in facilitated workshops. It guided focused discussions and offered a structured way to tackle the problem. An important feature was also that it allowed participants to try different judgements to see the consequences without a final commitment. This allowed them to re-evaluate their opinions. The applied facilitated workshop method was considered to fit in accustomed decision-making process, to offer a forum for constructive dialogue and to be open, equitable and auditable.

Decisions which concern a wide section of the population should be open and transparent (McDaniels et. al. 1999; Sauri 2002; Susskind 1996). One finding of this work is that transparency and communication could be clearly increased by applying the structured approach of decision analysis (Sinkko et.al. 2004, I). The decision-making process was made fairer and more competent by involving key players as has been proposed by, e.g., Renn et. al. (1995). The participation of key players increases the cost and complexity of the process, and the decision where to stop a participatory, analytical regime has to be made by seeking a balance between accuracy, time and resources. There is no need for analytical approach in recurrent decisions. People are accustomed to routine, repeated decisions where experience is available. Rare, complex problems such as large protective actions could evidently benefit from a facilitated workshop based on decision analysis.

The decision analytical approach offers a suitable framework to aggregate values, beliefs and preferences that are held by the different interest groups. In the case studies it helped the participants to tackle the problem in a logical and efficient manner. For example, when constructing the attribute or objective hierarchy, the key players were encouraged to think about all the factors that are important to them in this context. An important achievement of the induced discussion was that many definitions were clarified and others revised. But probably even more important was that it created a common understanding of the decision problem (Sinkko et. al. 2004, I). At a later stage, the participants were asked to consider explicitly the necessary trade-offs between the attributes. The given preference statements revealed the perceived importance of each attribute in relation to all the others. Thus, the analysis did not merely yield a ranking of the strategies investigated; it also revealed the reasoning behind them. The primary benefit of decision analysis is the improved understanding and risk communication. This is important because the decision taken needs to be explained and justified afterwards. In addition, it increases the level of commitment that is needed from all interest groups to carry out effectively any intervention agreed upon.

Susskind and Field (1996) have argued that face-to-face negotiation among key players could be the only way to settle the acceptable level of risk. The experiment conducted by Arvai (2003) supports this view. In the participatory decision-making process people were more supportive of the resulting risky decisions than participants in the control group. The risk was also perceived as being lower and the benefit higher in the participatory group. The process was seen to be fair, reasonable and amenable, allowing key players to announce their views and concerns. Slovic (1997) has argued that risk management could be developed by involving public in the process instead of trying to increase trust and to improve the communication. The experience gained in the workshops strongly supports this view, notably the latest workshop where the risk communication issues were discussed with the participants (Sinkko et. al, 2004).

The workshops method conforms to the basic principles in nuclear emergency management i.e., justification and optimisation of protective actions as is stated by international organisations. It also exemplified that the chosen setting can be fruitfully applied to the planning of early as well as later phase protective actions in advance. The participants considered workshops and decision analysis techniques applicable during the later phase in a potential real situation. Its suitability was not rated as high as for planning in advance. The applicability for the early phase, which is very intense and rapidly developing, had the lowest rating.

The realistic nature and the disciplined process of a facilitated workshop and commitment in decision-making yielded understanding as to what information should be collected and in what form. It was found to be important that information collected and given to key players is in the proper form for decision-making as is described in Decision Analysis (Hämäläinen et al. 2000, VI; Ammann et al. 2001, VII). The aggregation of unstructured information could easily result in a collection of views which cannot be utilised in the decision-making process.

Experts are tempted to do research and publish the results in a form suited to scientific reporting rather than adapted to decision-making. They may resist providing any results at all until they are definitive enough to withstand peer scrutiny (Brown 2003). However, experience suggests that with insufficient information a facilitated workshop conducted early on will guide and focus subsequent research and collection of data. Every workshop has made proposals for research topics and data collection (Hämäläinen et al. 1998, V; Hämäläinen et al. 2000, VI; Ammann et al. 2001, VII). As a consequence, a workshop could reduce collecting masses of data that will make no difference to any decision. Technical meetings or the stakeholder networks could shed light on information needed in decision-making. However, the final weight on the importance of information could be obtained after the trade-offs have been made. It indicates the topics which are most important in decision-making and shows where allocation of resources to research would be most beneficial. One explanation of the observed poor adequacy of consequence assessment data for decision-making is that reactor accidents are rare. This allows experts to be insensitive to decision-makers' interests and the flaw to be revealed (Brown 2003).

The information package to be given for decision-makers should comprise technical information to help to understand the accident scenario and selected information on how to make a reasonable choice between alternative actions. During this work much insight was gained in objectives and attributes people consider in deciding on protective actions. This was achieved by writing down the definitions of attribute before preparatory meetings and workshops and showing them to the co-workers and participants of the workshops. This helped communication and saved time in workshops (Hämäläinen et. al. 2000, II). Because in an accident so many technical issues have to be coped with, it would also be reasonable to prepare more material for workshops than is recommended in the Decision Analysis. The Decision Analysis assumes that participants are the problem owners i.e., familiar with the issues. That is not necessary the case in nuclear emergency management. For example, it was found useful to prepare material on health risks similar to radiation (Sinkko et. al. 2004). A skeleton of a decision model with a tentative ranking of options could be sent to the participants beforehand. In workshops the model could be discussed and revised. The judgements given should be clear and open to debate. This view, which is also supported by research, that even when all aspects of all alternatives are fully described, people have difficulties in making explicit trade-offs themselves (Gregory, Lichtenstein and Slovic 1993).

The work revealed the need to further develop the methods to assess the radiological and cost implications of countermeasures realistically. The models are typically able to calculate areas of deposition, the fallout pattern and rough radionuclide concentrations in foodstuffs. That helps to cope with the situation, but the information is not in the form needed for decision-making. In order to provide more realistic consequence assessments it is necessary to take production, economic, demographic and geographical information into account. Also, feasibility and constraints, such as logistics and legislation of protective actions, were found to need further investigation. No regulations or plans seem to exist in the EU or in the Nordic countries to dispose of radioactive waste that may result from decontamination or other protective actions.

Decontamination, disposal of contaminated products such as milk, grass, fly ash, and compensation for property and products after a nuclear accident may raise legal questions (French et. al. 1996; Ammann et. al. 2001, VII). Nuclear energy acts, the radiation safety act and nuclear liability acts aim to cover domestic accidents in many countries which have their own nuclear energy production. Transboundary accidents build up a somewhat different situation as regards compensation. The conventions ('Paris Convention' 1964/1982, 'Brussels Supplementary Convention, 1964/1982, 'Vienna Convention, 1963 and 'Compensation Convention' 1997) do not fulfil completely compensation issues (OECD/NEA 2000). Many nuclear energy producing countries are not members of any these conventions.

Compensation for damages will need political decisions in actual accident situations. In domestic accidents and in accidents in those countries which are parties to the relevant international conventions on third-party liability there is a legal framework for compensation. There are no other specific regulations for compensation for damages caused by a nuclear accident. Compensation issues have led to many trials. Susskind and Field (1995) have proposed that first the responsibility has to be accepted, the legal process has to be fair and timely, and all unintended damages should be compensated for, not offering money in return for taking risks.

Information technology played an important role in the last workshops (Amman et. al 2000, VII; Sinkko et. al 2004). It was a new feature of the workshop, i.e. that the participants could directly interact and experiment with their own decision models, and they encountered no noteworthy problems in doing so. Since Web-HIPRE is a Web-based application and can be accessed by the ubiquity of Web browsers, an easy-to-use user interface that required very little introduction was provided (Hämäläinen and Mustajoki 1998, Mustajoki, and Hämäläinen 2000). The complete description of decision support tools for individual as well as for workshops or negotiation is given by Hämäläinen (2004, see also www.decisionarium.hut.fi). With this software support, instant aggregations of group decision and a consensus model were easily obtained. A special web site was created for the two last workshops. A page comprising analogous facts to the information package could be valuable in a real accident situation; updated results of the decision analysis could also be made available. Internet technology offers a fast and open channel to deliver information equitably and increase common knowledge of all key players.

The technical equipment used during the workshop is easily installable at different locations. This facilitates the use of the system, for example in situations where key players' mobility is restricted. This was demonstrated by the ease with which the equipment was transported and installed at the meeting location. Since the software is Internet-based, it enables remote participation and the use of external information, such as video material from the accident location. The equipment and state-of-the-art software support greatly eased the conducting of the workshop. It allowed the participants to concentrate on the issues at hand and not too much time was spent mastering unfamiliar technology.

After the facilitated workshops reported here and in many workshops organised in seven European countries within EUs research project EVATECH the participants were asked to evaluate the workshop method (http://www3.sckcen.be/samen/). Almost all participants considered the workshop method as very applicable in planning protective actions. This provides strong evidence that the workshop method fit for use. Although the method has been positively received by different types of key players more workshops should be organised to make the approach more known and more research are needed in planning of protective actions.

Acknowledgements

I am very grateful to numerous people; my colleagues, my team members, experts in other organisations, and universities, and friends who have influenced the work. I owe my warmest thanks to Professor Sisko Salomaa, Director of Research and to my friend, Depute Director Raimo Mustonen for their encouragement during this study and for their comments.

I wish to express my sincerest thanks to the supervisor of this thesis, Professor Raimo P. Hämäläinen, for many valuable comments and constructive criticism. I am also very grateful for the opportunity to work for many years with Professor Raimo P. Hämäläinen and Professor Simon French. I have learnt a great deal from many scientific discussions and valuable guidance on Operational Research. I wish to express my gratitude to Professor Pekka Korhonen and Professor Timo Mäkeläinen for guiding me to Decision Analysis at an early stage.

I thank Dr. Per Hedemann-Jensen and Dr. Jutta Geldermann for reviewing the thesis with professional skills and for their constructive criticism.

I wish to express my special thanks to the former Head of Department Anneli Salo (retired) for her advice and vital encouragement. She has taught me over many years of collaboration the importance of common sense in emergency management. My warmest thanks go to many co-workers: Ole Walmod-Larsen and Michael Ammann, who has assisted the work in a creditable manner. I also wish to thank my colleagues and co-writers Riitta Hänninen, Eila Kostiainen, Mats Lindstedt and Jyri Mustajoki. I wish to express my thanks to the secretaries Anu Haglund, Jaana Joenvuori, Raisa Tiililä and Minna Westerlund for their help in finalising this thesis and related publications. My warm thanks also go to all those who have enthusiastically participated in the workshops for freely giving their advice, value preferences and judgements. I am grateful to Michael Cox and Jaana Joenvuori for improving my English.

Finally, my warmest thanks to all my family for their support and patience during these years.

October 2004 Kari Sinkko

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Radiation Protection Dosimetry (2004), Vol. 109, Nos 1-2, pp. 127–132
DOI: 10.1093/rpd/nch258

EXPERIENCES IN METHODS TO INVOLVE KEY PLAYERS IN PLANNING PROTECTIVE ACTIONS IN THE CASE OF A NUCLEAR ACCIDENT

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A widely used method in the planning of protective actions is to establish a stakeholder network to generate a comprehensive set of generic protective actions. The aim is to increase competence and build links for communication and coordination. The approach of this work was to systematically evaluate protective action strategies in the case of a nuclear accident. This was done in a way that the concerns and issues of all key players could be transparently and equally included in the decision taken. An approach called Facilitated Decision Analysis Workshop has been developed and tested. The work builds on case studies in which it was assumed that a hypothetical accident had led to a release of considerable amounts of radionuclides and, therefore, various types of countermeasures had to be considered. Six workshops were organised in the Nordic countries where the key players were represented, i.e. authorities, expert organisations, industry and agricultural producers.

INTRODUCTION

Openness, transparency and participation of the key players are all important factors for balanced decision-making in public issues. The research in key players' involvement in environmental decisions has led to the conclusion that if relevant parties are not engaged in the decision-making process the policy will fail and the final decision 'might please almost no one and certainly infuriates many'[1,2]. Key players or stakeholders comprise responsible administrators and organisations, politicians as well as representatives of affected citizens and other actors who will and are likely to take part in decision-making. International organisations in radiation protection have recognised this importance of prompt, open and transparent decision-making based on scientific facts and social judgements[3]. They have stressed that the basis of the decision must be perceived by the public and all relevant factors concerning the decision should be considered in a rational manner.

The consequences of an accident and the intervention will depend substantially on the event, the nuclide composition and on the season. The choice of intervention measures is also linked to the legislation and the economy of the country potentially affected. Because of this diversity, and constraints and deficiencies in the consequence calculation tools in the past, the international organisations could not have taken into account all potential scenarios and all national circumstances. Recommended intervention levels have been based on reasoning and generic cost-benefit optimisation of protective actions, which most likely will protect the population in an appropriate way. Recommendations cover general and readily available countermeasures. The detailed planning has been left to national organisations in each individual country worldwide. This study is a response to the international call for national planning of protective actions in advance.

There are different persons and organisations that are responsible for the decision-making and for the implementation of countermeasures at different phases of an accident. At the accident site the operator or licensee for the practice, e.g. operation of a nuclear power plant, is in general responsible for controlling the event. The licensee may also be the first organisation to take the initiative in implementing off-site protective actions close to the site based on emergency plans. In the longer term the decision-making is subject to a country's administrative and legal system where the key players will have an important role and are making decisions on protective actions.

Later phase protective actions, which usually concern the society widely, are typically based on group decisions. The key players may have different views on the problem and the relevant objectives. The players can be engaged in the decision-making process in various ways: advisory committees, planning cells, citizen juries, mediation etc.[1]. The involvement often increases the costs and complexity of the process. Individual participation methods have apparent advantages but some are also prone to shortcomings in certain problems that have led to criticisms[4,5]. Many methods allow participants to select the 'easy' alternative. The decision might not be accountable and long-term planning might be neglected if the participants are not responsible for implementation of the choice made. The working

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procedures and the efficiency of the use of time in the group meetings have also often been considered to be poor[2,6]. The reported experience emphasises the importance of having clear procedures and methods for the decision-making process. Not all participatory methods articulate factors and judgements systematically and openly to be viewed by everyone concerned.

The objective of this work in addition to planning countermeasures in advance is to develop methods to include concerns and issues of all key players openly and equally in the decision. The approach applied employs a group process where responsibility is placed on the participants to assimilate information and to provide judgements. It has a clear structure based on the decision analysis which provides a reasoning and learning framework that intertwines the beliefs, preferences and value judgements of the participants and achieves a transparent ranking of the strategies available. Decision analysis has a major role in facilitated workshops. It guides discussions and offers a structured way to tackle the problem. An important feature is also that it allows participants to try different judgements to see the consequences without a final commitment. This allows them to re-evaluate their opinions. The essence of decision analysis is to break down a complicated decision into small, manageable pieces that can be dealt with individually and then recombined logically. The main phases in this one-step-at-a-time approach are: identification of relevant objectives and attributes, definition of action alternatives, assessment of the consequences in each action, judgement of the relative importance of consequences and analysing how sensitive the resulting ranking of actions is to changes in the values in consequence assessment and trade-off judgements[7].

Decision analysis techniques have been applied to solve societal problems such as environmental decisions and energy policies[1,5,8,9]. The papers by Apostolakis and Pickett[10], Hämäläinen[11–12], Keeney and von Winterfelt[13] and Keeney[14] are examples of studies of problems which also have connections to nuclear emergency management. In the field of nuclear emergency management, decision analysis has been applied and facilitated workshops have been organised in various countries[15–17]. International organisations have demonstrated how justification and optimisation could be applied to planning protective actions[18]. For example, the IAEA aims to provide a benchmark against which national plans can be compared. The planning is based on a simple cost–benefit analysis.

This paper reports and summarises observations from different types of facilitated workshops. The first workshops followed a two-day decision conferencing approach. Other forms of decision conferences have also been suggested, e.g., the spontaneous decision conferencing concept, where the whole process can be accomplished in just a few hours and with minimal arrangements[6]. In problems involving experts and higher level policy makers time is always limited. Therefore, this more concise type of approach was seen to be practical. The shorter type workshops necessitate extensive collection of background information and preceding preparatory meetings but this kind of process was seen to comply with conventional emergency management. Another approach is to apply an interview technique in order to analyse the decision from the perspective of individual stakeholders. This approach was also applied in this study.

FACILITATED WORKSHOPS AND STAKEHOLDER NETWORKS

The aim of the stakeholder network method is to collect information for decision-making and build up a forum for regular communication between the key players[19]. The object of the facilitated workshops is to evaluate systematically the protective action strategies in such a way that concerns and issues of all key players could be considered openly and taken into account equally in the decision. An important outcome of the work is the creation of preconditions for participatory decision-making in case of a nuclear accident.

A series of facilitated workshops have been organised in the Nordic countries to analyse protective actions and develop methods for key player participation in case of a nuclear accident. The workshops were jointly arranged by the Nordic cooperation organisation (NKS, Nordic Nuclear Safety Research) and the University of Leeds, in Denmark in 1992 and in Sweden in 1995, by the STUK–Radiation and Nuclear Safety Authority and the Helsinki University of Technology in Finland in 1997, 1998, 1999 and 2001. STUK was responsible for the coordination, development of the accident scenarios, consequence assessments and for the contacts with the key players. University of Leeds and Helsinki University of Technology were responsible for the decision modelling and analysis approaches, and for the implementation of the decision support software as well as for the facilitation of the workshops.

The NKS organised the first two workshops held in Denmark and Sweden[20,21]. The members of these workshops were local government officials, emergency planners and members of the radiation protection community from all the Nordic countries. The two subsequent workshops and decision analysis interview were conducted within the fourth Framework Programme of the EU[22,23]. The last Finnish workshop was funded by local sources[24].

The planning of protective actions and the participatory method development is based on case studies

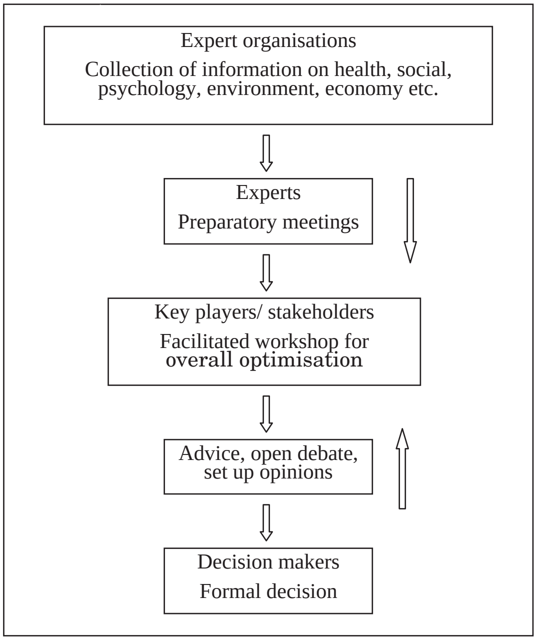

Figure 1. A schematic view of an ideal type decision-making process applicable in the planning of protective actions.

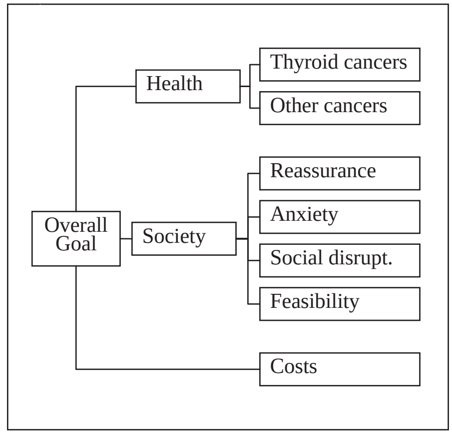

Figure 2. Value (or attribute) tree used in the workshop, which considered countermeasures to reduce the dose received from consumption of dairy products contaminated by radionuclides.

where key players were invited to consider a scenario of a hypothetical but realistic nuclear accident. It was assumed that a core-damage and containment leak accident had occurred at a nuclear power plant, leading to the contamination of the environment. To make the cases more realistic the accident sequence was typically taken from probabilistic reactor safety studies (PSA) performed by the NPP and STUK safety experts. It was also considered important that the current emergency management process of the administration was followed closely and that all the relevant players were represented at the meetings. Experience gained from this work supports the view that facilitated workshops fit well in the planning phase in a decision-making process where the key players with expertise in different areas analyse and evaluate alternative options to be given for final debate before the formal decision is taken (Figure 1). Contacts were made and preparatory meetings held prior to the workshops. This would also take place in real emergencies.

Several protective actions and the bundle of actions, i.e. strategies, were selected to be considered in the workshops. The workshop held in Denmark considered countermeasures in a situation where early phase protective actions had been taken and decisions on the later phase protective actions were to be considered. The main issue was to consider whether to relocate people in certain areas. The theme in the second Nordic workshops was the decision of clean-up actions in inhabited areas. The first Finnish workshops focused on the early phase countermeasures, i.e. administration of iodine tablets, sheltering and evacuation. The value tree model and definitions of attributes related to the decision of early phase protective actions were studied in depth. The different ways of incorporating uncertainty into the emergency management was studied in these workshops and in the interview study. The task of the last workshop was to plan countermeasures to reduce the dose received from consumption of dairy products contaminated by radionuclides. The alternative actions were: no action, provision of uncontaminated fodder, milk processing to cheese or butter and banning (cf. Figure 2).

The simulation of the radiological situation and the generation of countermeasure strategies, together with the assessment of their consequences, were done in advance. The participants were given information comprising thematic maps of the radiological situation showing an animation of the dispersion, dose values and assessments of health and economic consequences. This information was also provided in the form of consequence tables. The possible precautionary actions taken to protect the population were mentioned. A list of predefined attributes, the parties involved in decision-making and their duties were attached. All in all, the package was designed to contain all the relevant information necessary for the participants to understand the accident situation and to be able to make an informed decision on the countermeasures.

At the beginning of the workshops the list of attributes and the value tree were presented and introduced for discussion (Figure 2). The participants were urged to go through, revise, remove, add and re-define any attribute they wished. Eventually, the group agreed on the final set of attributes. The 'hard' attributes, i.e. number of cancer cases and costs were calculated in advance but the 'soft' attributes like social disruption and anxiety were directly rated during the workshops. A decision model was constructed and value or utility analyses were performed including sensitivity analysis with commercially available software. The results were discussed at the end of the workshops.

DISCUSSION

The workshops aimed to elicit protective actions or strategies of which the scale, timing and duration were optimised in the given situation (optimisation in the sense of radiation protection). Decision analysis techniques can be used to evaluate and identify the best strategy, i.e. to rank strategies. The justification of countermeasures embodies many value judgements and is implicitly included in the analysis. If all possible alternatives are considered, the best ranked option should also be justified. In the traditional vocabulary of radiation protection the optimal choice is thus found.

There should be a clear understanding of the countermeasures and factors affecting the decisions. The timing, duration and target area of the actions, and the group aimed to be protected by the actions could be quite easily assessed and should be clearly defined. The objectives and attributes are not self-evident. In the workshops, a lot of time was spent on defining the factors and the wording used in the value elicitation. Especially, intangible attributes such as anxiety and reassurance can easily be interpreted differently. It seems to be beneficial to define the attributes in advance in order to save time and to guarantee that all key players will understand their meaning in the same way. The definition of attributes in advance is contrary to the standard way of using decision analysis and possibly leads to such biases as availability or anchoring. However, nuclear accidents are rare and the key players are not very familiar with the radiological issues or the related terminology. It was found that in order to harmonise the discussion it is practical and efficient to start with a pre-defined, preliminary value tree model of attributes. The participants were asked to fill in a questionnaire after the workshops in order to find out their opinions on the decision analysis and the workshop method. The questionnaire confirmed that the participants were rather satisfied with the pre-defined attributes and ensured that all relevant factors were included in the model.

Open and transparent societal decisions are desired both by the public and politicians[5]. One finding of the study is that transparency and communication could be clearly increased by applying the structured approach of decision analysis. The decision-making process was made fairer and more competent by involving key players. Susskind and Field[2] have argued that face-to-face negotiations among the key players could be the only way to settle the acceptable level of risk. However, the active participation of all the key players increases the cost and complexity of the process, and the decision where to stop an analysis has to be made by seeking a balance between elaborateness, time and the resources available. There is no need for an analytical, participatory approach in recurrent decisions. People are accustomed to routine decisions where experience is available. However, rare, complex problems such as large protective actions can benefit from the use of facilitated workshops based on decision analysis.

It is important to learn to see where in the decision-making process decision support in the form of a workshop would be appropriate. Facilitated workshops do not fit comfortably in the decision-making process applied commonly nowadays as a forum for making final decisions[21]. Preparation of a decision is divided into so many phases carried out by many responsible people that a single decision-making point cannot often be identified. In a workshop a single decision-making point is pre-supposed. Usually, politicians and authorities do not participate in the consequence assessment or in the preparation or evaluation of a decision. They tend to wait, avoid the commitment to the outcome and distance themselves from it if necessary[1]. They expect prepared advice from the experts[10,25]. Experience gained from this work supports the view that facilitated workshops fit well in the planning phase in a decision-making process where the key players with expertise in different areas evaluate the alternative policy options in an open discourse before the final, formal decision-making.

It was found to be important that the relevant expert organisations carry out the technical calculations and reports in such a way that the politicians and authorities can understand the problem and the consequences of the decision options. The information collected should be in a suitable form for decision-making as is described in the decision analysis. This helps communication and saves time. The aggregation of unstructured information could easily result in a collection of views which cannot be utilised in the decision-making process. Experts are tempted to do research and publish the results in a form that is more suited to scientific reporting rather than adapted to decision-making. They may resist providing any results at all until they are definitive enough to withstand peer scrutiny. However, experience suggests that with insufficient information a facilitated workshop conducted early on will guide and focus the subsequent radiological research, model development and collection of data. Technical meetings can shed light on the information needed in decision-making. However, the final weight on the importance of information could be obtained after the trade-offs have been made. It indicates the topics that are the most important in decision-making and shows where the allocation of resources into research would be most beneficial. Every workshop has made proposals for the necessary research topics and data collection.

Most participants were not familiar with this type of structured approach of decision analysis and opinions were divided about it. Some found that the benefits were obvious but some did not feel comfortable with the modelling tools and had problems in understanding the procedures, such as weighting of attribute scales and incorporation of uncertainties (utility analysis), in the decision-making process. The definition of the attributes and the countermeasures, and decision table were easily adopted. One reason why some were reluctant to take part in decision analysis might be that they were expecting a recurrent decision-making process where experience is available. The method had seldom been applied in radiation protection and before the workshops there was no training for participants. Only a few hours were spent on the issues and, consequently, there was not enough time to explain in detail all the decision analytical methods used during the workshops. In the future new applications of the approach to appropriate problems are likely to increase acceptance and understanding of the techniques.

CONCLUSIONS

Decision analysis offers a suitable framework to aggregate values, beliefs and preferences that are held by the different interest groups. In the case studies, it helped the participants tackle the decision-making problem in a logical and efficient manner. For example, when constructing the attribute tree from objectives, the key players were encouraged to think of all the factors that are important to them in this context. An important achievement of the induced discussion was that many definitions were clarified and others revised. Probably the most important benefit was that the process created a shared understanding of the decision problem. At a later stage, the participants were asked to consider explicitly the necessary trade-offs between the attributes. The given preference statements revealed the perceived relative importance of each attribute. Thus, the analysis did not merely yield a ranking of the strategies investigated but it also revealed the underlying reasoning behind it. The primary benefit of a decision analysis is the consequent improved understanding and communication. This is important because decisions taken need to be explained and justified afterwards. In addition, it increased the level of commitment that is needed from all interest groups to carry out interventions agreed upon.

The experience gained strongly supports the use of the facilitated workshop method to tackle a decision problem that concerns many different key players. In the study, the participants considered the workshops and the decision analyses to be very useful in the planning of the relevant actions in advance. They also expected a similar approach to be applicable in a real accident situation, although the suitability was not rated as high as for planning. The suitability of the method for the early phase of an accident was rated the lowest.

The pros and cons of the facilitated workshop method can be compared with the conventional approaches. The general goal is that key players would be better prepared for an accident situation. All participatory methods also create a network of key players. Facilitated workshops provide the participants with an open forum for discussing openly the values behind the decision. The stakeholder network can evaluate and augment generic countermeasures but all the possible and feasible protective actions cannot be justified and optimised in depth. The ranking of protective actions depends on trade-offs and is thus dependent on the problem at hand.

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Multiattribute Risk Analysis in Nuclear Emergency Management

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Radiation protection authorities have seen a potential for applying multiattribute risk analysis in nuclear emergency management and planning to deal with conflicting objectives, different parties involved, and uncertainties. This type of approach is expected to help in the following areas: to ensure that all relevant attributes are considered in decision making; to enhance communication between the concerned parties, including the public; and to provide a method for explicitly including risk analysis in the process. A multiattribute utility theory analysis was used to select a strategy for protecting the population after a simulated nuclear accident. The value-focused approach and the use of a neutral facilitator were identified as being useful.

KEY WORDS: Nuclear emergency management; risk analysis; multiattribute utility theory (MAUT); decision conferences; uncertainty

1. INTRODUCTION

In Europe, the Chernobyl nuclear accident has focused attention on the need for developing better structured and coherent procedures for decision making on protective actions in nuclear emergency management. A nuclear accident develops fast, has major impacts on the environment and society, and is the subject of highly emotional feelings and beliefs among the public.

Decisions on countermeasures are not only driven by the need to avert the radiation dose to the population but are based on complex and multiattribute problems, involving, for example, monetary costs and sociopsychological factors, such as stress and anxiety. These decisions have far-reaching consequences, yet they often have to be made under severe time-pressure constraints and conditions of uncertainty. Moral and ethical values held by decision makers and stakeholders are as important as the technical issues about the consequences of radiation. Even some of the underlying assumptions in neutral risk assessments may contain value judgments. This complex situation thus places high demands on the decision-making processes. It is important to be able to identify and process both factual issues and value issues; see for example the Values in Decisions On Risk (VALDOR) Symposium[1] for a discussion.

In Finland, the radiation protection authorities have therefore seen a potential for applying multiattribute risk analysis in nuclear emergency management, especially in the training and planning processes, to deal with the conflicting objectives, different parties, and uncertainties that are inherent in such complex situations. This type of an approach is expected to be of assistance in at least the following three areas: to ensure that all the relevant attributes are considered in decision making; to enhance communication between the concerned parties, including the general population; and to provide a method for explicitly including risk analysis in the process. This article discusses some recent research that has been done on this subject in Finland.

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This study was part of RODOS (Real-time Online DecisiOn Support), an ongoing European Union (EU) project on developing a support system for nuclear emergency management. The study builds on previous work done in this field,[2–7] from which the following conclusions have been drawn:

1. Decision conferencing is a promising way to support the process.
2. The structured approach offered by multiattribute risk analysis is useful.
3. Good communication and understandable presentations of the data and options are essential.
4. The use of utility theory for risk handling is difficult, as the participants are not familiar or comfortable enough with the techniques.

An important goal of these exercises was thus to familiarize the decision makers with multiattribute risk analysis techniques, as well as to build a way of thinking that could be used in the improbable event of a real accident. The approach used was the spontaneous decision conferencing technique.[8] That is, a fast type of decision conferencing was used to ensure that the analysis could be conducted in the limited amount of time available. Hämäläinen *et al.*[7] discuss how this type of decision conferencing was applied.

Another possible approach is the decision analysis interview technique.[9] In a decision analysis interview, the analysts work individually with each decision maker to build the model and to elicit preferences. By focusing separately on each decision maker, analysts can ensure that all issues are clarified and that no misunderstandings arise; that is to say a better understanding of the complexities involved in the decision situation is achieved. This type of approach has been tested in another project with a similar nuclear-emergency setting.[10]

Decision analysis techniques have also been used in similar risk analysis approaches to environmental decisions and energy policies.[11–15]

This article presents a short description of nuclear emergency management in Finland and the RODOS project, followed by a general discussion of using decision analysis in nuclear emergency management and a case study. Main results are described and the needs for further research are clarified.

2. NUCLEAR EMERGENCY MANAGEMENT IN FINLAND

The basic principle in emergency management of nuclear accidents in Finland is that each administrative branch is responsible for emergency responses and preparedness arrangements in their own sector of authority. Hence, each ministry decides on countermeasures in their jurisdiction and presents matters to the State Council of Finland that require political commitment. The Ministry of the Interior is responsible for the overall coordination of actions within the central government, especially in the early phase of an accident.

The Radiation Act (592/1991) and Radiation Decree (1512/1991) on radiological protection determines the general principles taken into account in the protection of people against ionizing radiation. In exceptional radiation situations, the Ministry of the Interior is responsible for the planning, coordination, and overall leadership of urgent protective measures. The central legislation covering emergencies is the Act on Rescue Services (561/1999; which includes fire protection, rescue services, and civil protection). In the acute phase of an accident, this act delineates the rights and responsibilities of each administrative body involved, and the urgent protective measures to be implemented, such as sheltering of people and cattle, evacuation, decontamination, and other actions described in the contingency plans.

In domestic accidents, these operations are led by the regional fire chief (regional cooperation for rescue purposes is arranged between several municipalities). All relevant local authorities are represented in the steering group assisting the fire chief. At the province level, the province administration board—with all relevant sectors represented—and at the national level, the Ministry of the Interior, have the right to give orders related to rescue operations.

For decision making, all other relevant laws are also valid, and the corresponding authorities are responsible for decisions in those sectors. The distribution of responsibilities is as follows:

1. The Ministry of Social Affairs and Health is responsible for the health protection of the population (advice on iodine prophylaxis, control of drinking water, psychological aid, medical treatment, etc.), and for providing logistics for evacuated people.
2. The Ministry of Trade and Industry is responsible for food and trade restrictions. Reporting to the ministry are the National Food Administration Authority, which is responsible for food sold in retail stores, and the National Emergency Supply Agency (HVK), which is responsible for preparedness and planning of food supply for exceptional conditions.

3. The Ministry of Agriculture and Forestry is responsible for issues related to agriculture, forestry, and fisheries, and for the implementation of the agricultural and fishing policy of the EU.
4. The Ministry of the Environment is responsible for housing relocated population groups and reclamation of contaminated land (waste from decontamination).

Other relevant ministries and agencies in accident situations include the Cabinet Information Unit, which coordinates information provided to the public; the Ministry of Foreign Affairs, responsible for information provided to the foreign media on Finnish accidents; and the Ministry of Transport and Communication, responsible for communications (through the Finnish Broadcasting Company) and transportation-related issues.

The cases studied in this report were conducted in cooperation with the Radiation and Nuclear Safety Authority (STUK)—a regulatory body for radiological practices and nuclear safety, subordinate to the Ministry of Social Affairs and Health. The general duties of STUK regarding off-site management include

- assessing the radiation situation;
- predicting and assessing radiation-related health consequences;
- providing recommendations on countermeasures to other authorities; and
- performing radionuclide analyses.

The participants in these exercises are thus experts responsible for giving advice on appropriate countermeasures to political decision makers.

3. RODOS

Partly due to the varied response to the Chernobyl accident, both in and beyond the former Soviet Union, the European Commission proposed the development of RODOS, which aims to provide consistent and comprehensive support for off-site nuclear emergency management. It is designed to assess, present, and predict the consequences of an accident, and support the decision makers in choosing appropriate countermeasures. Ehrhardt and Weis[16] and the RODOS Web site[17] provide an in-depth description of the project.

The RODOS software is designed to be a decision support system for off-site nuclear emergency management. This implies that RODOS must be able to support a wide variety of decision makers at several different stages of an accident. The decision support provided is divided into four levels (as shown in Table I).

Table I. Decision Support Levels in Real-Time, On-Line Decision Support (RODOS)

Level 0	Acquisition and checking of radiological data, and their presentation (directly or with minimal analysis) to decision makers, along with geographical and demographic information available in a geographical information system
Level 1	Analysis and prediction of the current and future radiological situation (i.e., the distribution over space and time in the absence of protective actions) based upon monitoring and meteorological data and models
Level 2	Simulation of potential protective actions (e.g., provision of shelter, evacuation, issue of iodine tablets, food bans, and relocation), in particular, determination of their feasibility and quantification of benefits and disadvantages
Level 3	Evaluation and ranking of alternative protective action strategies in the face of uncertainty by balancing their respective benefits and disadvantages (e.g., costs, averted dose, stress reduction, social and political acceptability) taking in account societal value judgments as perceived by decision makers

Note: From Ahlbrecht *et al.*[2]

On the first level, RODOS merely organizes the incoming data and presents it to the decision makers. Increasing levels of support follow, ending at Level 3, where RODOS interacts with the decision makers, helping them to explore and develop their judgments and evaluations. In a sense, RODOS provides decision-making support only at Level 3; on the first three levels it mainly organizes and presents information.[2] The present study focuses on how Level 3 support could or should be implemented.

4. MULTIATTRIBUTE RISK ANALYSIS IN NUCLEAR EMERGENCY MANAGEMENT

Multiattribute risk analysis is a structured approach to decision making that employs systematic analyses to give decision makers a better understanding of the problem, and thus facilitates a better informed choice. The methodology of decision analysis can be implemented in a number of different ways. Keeney[18] divides the process into four steps: (1) structure the decision problem; (2) assess possible impacts of each alternative; (3) identify the decision makers' preferences and values, and (4) evaluate and compare alternatives. Other reviewers provide a more thorough description of fundamental decision analysis theory.[19–22]

The structured and systematic approach of multiattribute risk analysis helps decision makers go through each phase of the process in a logical and efficient manner. The methods include techniques for finding suitable alternatives among the various possible countermeasure strategies. Value trees help decision makers consider all factors that have an impact on the decision, including averted dose and cost, as well as sociopsychological and other factors.

Perhaps the greatest advantage of using multiattribute risk analysis is that it explicitly conceptualizes the underlying values in the decision-making process. When constructing the value tree, decision makers must think about which factors are important when deciding on countermeasures. At a later stage, they are asked to consider the necessary trade-offs and choose between them. The given-preference statements show how important each factor is relative to the others. The whole decision process thus follows a value-based approach.[23]

Decisions on countermeasures after a nuclear accident are plagued with uncertainties; for example, how severe the accident really is, what the weather will be, how the population will react, etc. It is necessary to consider these risks distinctly, and multiattribute risk analysis is a valuable tool in this process. Without such a tool, there is a danger that decision makers will implicitly add "safety margins" at any or each stage of the process, thus creating a safety "overkill." This is especially likely if there are several layers in the decision-making organization (e.g., experts, managers, and policy makers) with each group giving advice to the nexy level. This scenario is typical in nuclear emergency management.

Risk attitudes determine the acceptable risk levels, and sensitivity analyses reveal to decision makers how small changes in assumptions or data will affect the end result. Both give transparent results that can be assessed or modified at later levels.

A generic value tree can be shown to decision makers in the beginning of the process. This can help them choose the relevant factors and construct a value tree for that particular case. After a nuclear accident, there is often little time to make the far-reaching decisions on what countermeasures to employ. Using prestructured value trees is a way to save valuable time. By having a list of predefined attributes, the decision maker can quickly choose the relevant ones for that particular accident scenario and continue from there, confident that all important factors are included. Other parts of the process can also be preanalyzed. For example, sets of suitable risk attitudes can be presented to provide the decision maker with a starting point from which to proceed by making the necessary modifications to the suggested models.

The use of a neutral facilitator from outside the expert organization, as in decision conferencing, can also be beneficial to the decision-making process in nuclear emergency management. An outside facilitator familiar with decision analysis techniques can help decision makers in many ways. His or her experience with complex decision-making situations can steer the group to the relevant aspects and help them avoid typical pitfalls in the process—for example, "groupthink"[24] and biases caused by homogeneity in the group makeup. The facilitator's help might be needed especially in explaining mathematical concepts to nontechnical participants. A facilitator can ensure that all phases of the decision-making process are thoroughly examined, all relevant factors are included, and a well-founded decision is reached in the limited time available. For credibility reasons, the fact that there is an impartial facilitator involved, who does not belong to the organization making the decision, can also be important.

Depending on the goals of the process, the emphasis can be on different phases. Often, the "structuring" phase is very important in decision conferences involving multiple stakeholders. Facilitators successfully practice different approaches in the structuring phase, but the merits of these different approaches have not yet received much comparative analysis.[25]

Decisions on nuclear emergency management affect large population groups, and thus have important social and political impacts. The decisions taken must be explained and justified, and will be subject to critical evaluation long afterwards. Using decision analysis techniques will aid this process by providing a transparent and reconstructable process of decision making. The basis for the decisions can be found from the alternative countermeasures considered, the value trees used, and the preference statements given. Weighing the positive and negative consequences of each alternative provides a way to explain actions taken and actions omitted after the fact.

Decisions on countermeasures after a nuclear accident are almost always prepared by a group. The issues are complex, and participants from different areas of expertise must come together to find the right countermeasure strategy. Effective and clear models for communication are thus needed. The structured approach of multiattribute risk analysis can provide the group with a common framework from which to approach the issues. By defining each factor in the analysis and following a logical analytical sequence, multiattribute risk analysis enhances the communication between the concerned parties, and minimizes the risk of misunderstandings and confusion.

Multiattribute risk analysis provides a structured process of decision making. The method ensures that decision makers consider all aspects of the problem and explicitly bring forward their values and preferences. It is often the structuring and prioritization processes that bring the greatest gain from using a decision analysis approach.

5. CASE STUDY: EARLY-PHASE PROTECTIVE ACTION AFTER A NUCLEAR ACCIDENT

A series of decision conferences on nuclear emergency management were organized in Finland in the autumn of 1997 as part of the RODOS project. For a full report on these conferences see Hämäläinen *et al.*[7]

The decision conferences were held on the development of an early-phase countermeasure strategy for protecting the population after a simulated nuclear accident. Two simulated nuclear accident cases were used, and a total of four meetings were organized. The meetings were attended by national nuclear safety authorities and technical experts in the role of decision makers. In the case of a real accident, their job would be to assess the situation and give advice to higher level political decision makers (see Section 2).

The meetings were half a day long each and chaired by a facilitator, who was one of the authors (Hämäläinen). The facilitator guided the group through the multiattribute risk analysis techniques, and an assistant generated the model and performed the analysis on-line. The results were displayed on a wide screen. The software used put some restrictions on which analyses could be conducted and how the inputs could be given—for example, which elicitation techniques could be used, how uncertainties could be modeled, and how the results could be presented and analyzed. These limitations could be eliminated by using other software. It is important to note that the choice of software will influence the analysis, although the main issue is, of course, that the facilitator and analyst must be well familiar with the software and its capabilities.

In the first accident scenario, no uncertainties were assumed; however, in the second case uncertainty about the release was included. The 5%, 50%, and 95% release fractiles were calculated and presented to the participants.

These conferences focused on urgent protective actions, that is, iodine prophylaxis, providing shelter, and evacuation. The primary goals were to test the RODOS system and to study and extend the applicability of decision support systems for different situations. In the early hours of an accident, there is hardly time to model the decision to be taken; rather, the decision must be based on intervention levels developed and considered beforehand, and on guidance given by a decision support system. The conferences were designed to analyze how this modeling should be done and which factors are important. Whether to use prestructured value trees or other types of shortcuts is another issue that was studied. In the later phase of an accident, by contrast, there is usually both the time and the need to perform more extensive analyses.

International organizations have published their recommendations for generic intervention levels,[26] and in addition there are also suggested values for the trade-off between costs and averted dose. An important aim of the present work was to probe deeper into the recommendations, and to explicitly introduce the values and beliefs held by the decision makers in the decision-making process: the factors that need to be considered, the necessary value trade-offs, and how the uncertainties should be modeled and accounted for.

In the first session, a generic value tree (see Fig. 1) was constructed using a brainstorming approach. The value tree was designed to contain all factors that should be considered in deciding on countermeasures after a nuclear accident. At this phase of the analysis, no thought was given to the relative importance of the factors, which is why the first tree is rather large. Although a smaller value tree was later used in the actual analysis, this type of generic tree helps in ensuring that no significant factor might be inadvertently omitted. It can also be used afterward to show that all factors were initially considered in the process, including those that were later eliminated as having no significant impact on the decision. In the second accident case, the value tree in Fig. 2 was used in the final analysis. As can be seen, in the second scenario only six attributes were included.

The majority of the participants felt that this type of approach helped them to consider more aspects of the problem than they would otherwise have done. (Hämäläinen *et al.*[7] provide a detailed description of the participants' opinions and thoughts.) The use of a generic value tree from which the significant factors were developed especially helped to raise confidence in the analysis. The participants also felt that prestruc-

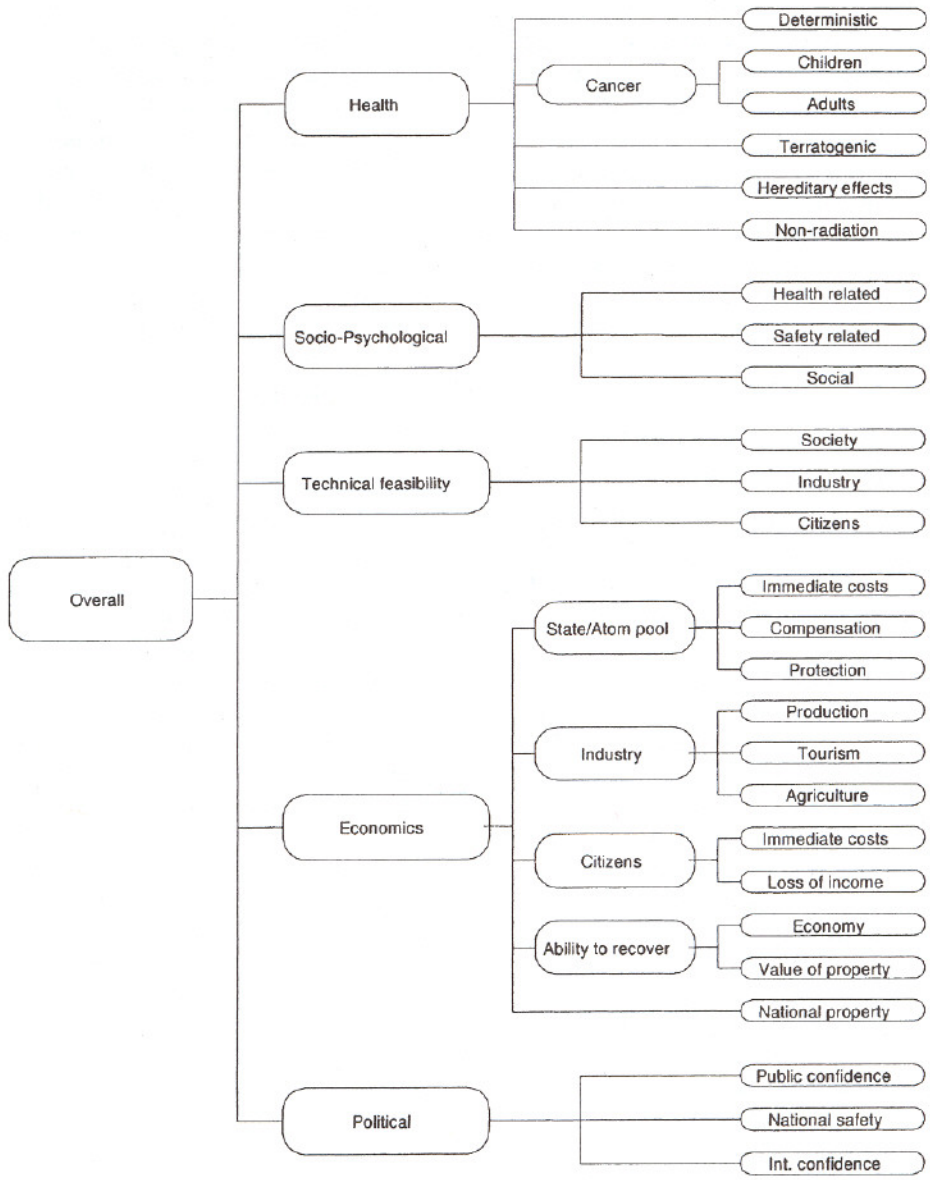

Fig. 1. Preliminary value tree constructed in a brainstorming session. It includes all possible factors that might need to be considered.

tured accident scenarios could be used to save time and help focus on the important issues. Predefined preference sets were, however, seen as more problematic.

In the conference, five different countermeasure strategies were constructed and analyzed. The impacts of each strategy are shown in Table II. Uncertainties regarding the magnitudes of the impacts are presented for three fractiles—5%, 50%, and 95%—corresponding to three different scenarios: optimistic, realistic, and pessimistic.

A three-stage system for constructing suitable strategies has been envisaged for RODOS.[16] This model would compute all possible combinations of actions and the areas where they would be used, and then apply certain decision rules to eliminate infeasible or clearly inferior strategies. The remaining options would be further analyzed, and a shortlist of suitable options would be generated. This model is not yet ready, however, so a different approach was followed. In particular, a group of experts created a set of alternative strategies, with the goal of covering a wide area of possible alternatives. The group con-

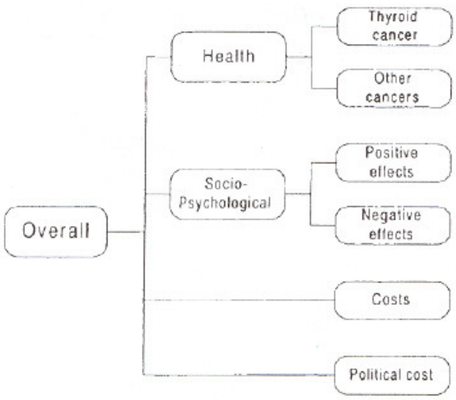

Fig. 2. Final value tree used in the second decision conference.

sisted of nuclear emergncy experts in planning of protective actions and who are in charge of preparing recommendations to the governmental decision makers. The strategies therefore ranged from doing nothing to evacuating a large area. It was pointed out to the participants that these options were only preliminary, and that the best course of action could probably be found by examining and combining a subset of the presented strategies. As the goal of this study, however, was to examine the use of multiattribute risk analysis techniques, the following set of optional strategies was seen as sufficient for this purpose:

Strategy 0: No additional countermeasures taken.

Strategy 1: Distributing iodine tablets and providing shelter in Rauma, a city of 30,000 inhabitants and 12 km south of the NPP. The number of people affected by sheltering and taking iodine is 40,600.

Strategy 2: Implementation of providing shelter in the city of Rauma and the closest areas around that city and distributing iodine tablets within an area almost to the city of Turku (i.e., 100 km away from the site). The number of people affected by sheltering is 56,200, and taking iodine is 88,500.

Strategy 3: Implementation of providing shelter in the same areas as in Strategy 2, but distributing iodine tablets in all areas affected by the accident (including both the cities of Turku and Tampere, for example). The number of people affected by sheltering is 56,200, and taking iodine is 1,023,200.

Strategy 4: Evacuation of Rauma after the cloud has passed the area, with provision of shelter and distribution of iodine tablets dur-

Table II. The Impacts of Each Strategy on the Different Attributes in the Second Phase of the Decision Conferences

Attribute	Unit	Fractile	Strategy 0	Strategy 1	Strategy 2	Strategy 3	Strategy 4
Health							
Thyroid cancer	Number of	5%	0	0	0	0	0
	cancer	50%	20	5	2	2	4
	incidents	95%	240	50	20	20	40
Other cancers	Number of	5%	0	0	0	0	0
	cancer	50%	22	20	20	20	12
	incidents	95%	320	286	288	286	204
Sociopsychological							
Positive effects	No change,	5%	0	100	10	10	0
	very positive	50%	0	75	50	45	40
	(0–100)	95%	0	50	90	80	80
Negative effects	No change,	5%	40	0	90	80	50
	very negative	50%	70	40	50	45	35
	(0–100)	95%	100	80	10	10	20
Costs	MECU[a]	5%	0.0	1.6	2.2	2.2	160.3
	MECU	50%	2.0	3.1	3.8	3.8	160.8
	MECU	95%	27.7	23.9	24.3	24.1	176.3
Political cost	No change—	5%	30	0	0	20	80
	very negative	50%	65	40	40	30	50
	(0–100)	95%	100	80	80	40	20

[a] MECU = million ECU, currently called EURO.

Lottery question:
Please select the number of cancer incidents, L, that would make you indifferent if you have to choose between having tht number for sure and a fifty-fifty chance of having either 250 cancer incidents or 0 incidents.

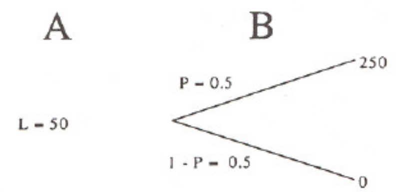

Fig. 3. Lottery question used in the second phase of the decision conferences.

ing the plume passage. The number of people affected by these actions is 40,600.

Because uncertainties were included, and the SMART (Simple MultiAttribute Rating Technique) and trade-off techniques were to be used for weighting, the shapes of the utility functions for the different attributes needed to be assessed.[19] The participants were asked to answer "lottery" questions of the type shown in Fig. 3. Resulting answers were tabulated individually rather than on the group level. The elicitation was done openly, and the whole group discussed the individual responses, so the resulting utility functions were used as the group's opinion. It was pointed out that the purpose of this exercise was not to produce a decision, but rather to help develop new insights into such a situation.

Only the utility functions for the two cancer attributes and the cost attribute resulted in nonlinear forms; the rest were linear. Figure 4 presents the shapes of the utility functions. The utility function for the costs attribute shows that the participants did not give much concern to money. It is only after the costs exceed about 130 million ECU that there is any significant decrease in the utility. When it comes to cancer, the participants seemed to be "risk seeking"; that is, they would rather take a risky option with the possibility of avoiding cancer totally, than the sure option of having some cancer incidents. This result might be partially due to the way in which questions were posed, and partially due to the fact that "zero incidents" was included. There is often a discontinuity point at zero, with the utility of reaching zero incidents being much higher than that of one incident.[27]

It is also important to consider the time frames involved. For example, thyroid cancer develops shortly after the accident. Leukemia, however, can appear decades later, and by then it can be difficult to identify the original cause of the disease. Should all of these effects be taken into account equally, or should some be discounted, and if so, which ones? How should the sociopsychological factors be assessed—the first reactions, or the feelings years after the accident, or a combination of both? These issues need to be analyzed in depth in future research.

The weights for the attributes were elicited both with the SMART technique[22] and with the trade-off method.[21] The nontechnical participants especially felt that SMART was easier to understand. The trade-off method was considered more difficult, and some participants had real problems understanding the underlying logic behind it. The resulting weights from both methods are given in Table III. The table also includes a case where only the 95% fractile (i.e., the pessimistic-case scenario) was used. That is, it was assumed that the 95% scenario would occur for sure, thus eliminating all uncertainties. This was done because it was noted that the decision makers had a tendency to concentrate on the worst-case scenario at the expense of the more likely ones. Therefore, it was seen as fruitful to examine what types of decisions such an approach would produce.

The resulting ranking when using the SMART method is presented in Fig. 5. The ranking for the pessimistic-case scenario is shown in Fig. 6. As can be seen from these figures, considering only the pessimistic-case scenario leads to a much higher level of intervention.

A linear additive utility model was used in the analyses. Keeney and von Winterfeldt[28] and Clemen[19] provide a more in-depth discussion on this model's validity and limitations.

Looking at the results, an observation can be made. The impact on cancer and costs in Table I is in many cases the same regardless of what strategy is chosen; Strategy 0 is worst in terms of thyroid cancer and Strategy 4 in terms of costs, but the remaining strategies score about the same on the cost and cancer attributes. Consequently, their ranking will be solely based on how well they score on the other attributes, for example, political costs. Nevertheless, most of the discussion emphasized the cancer attribute, and it also received a high weight in the analyses. How is it that the cost and cancer attributes cannot discriminate between Strategies 1, 2, and 3? One reason for this finding is the sparse population density and hence small number of cancer cases in the

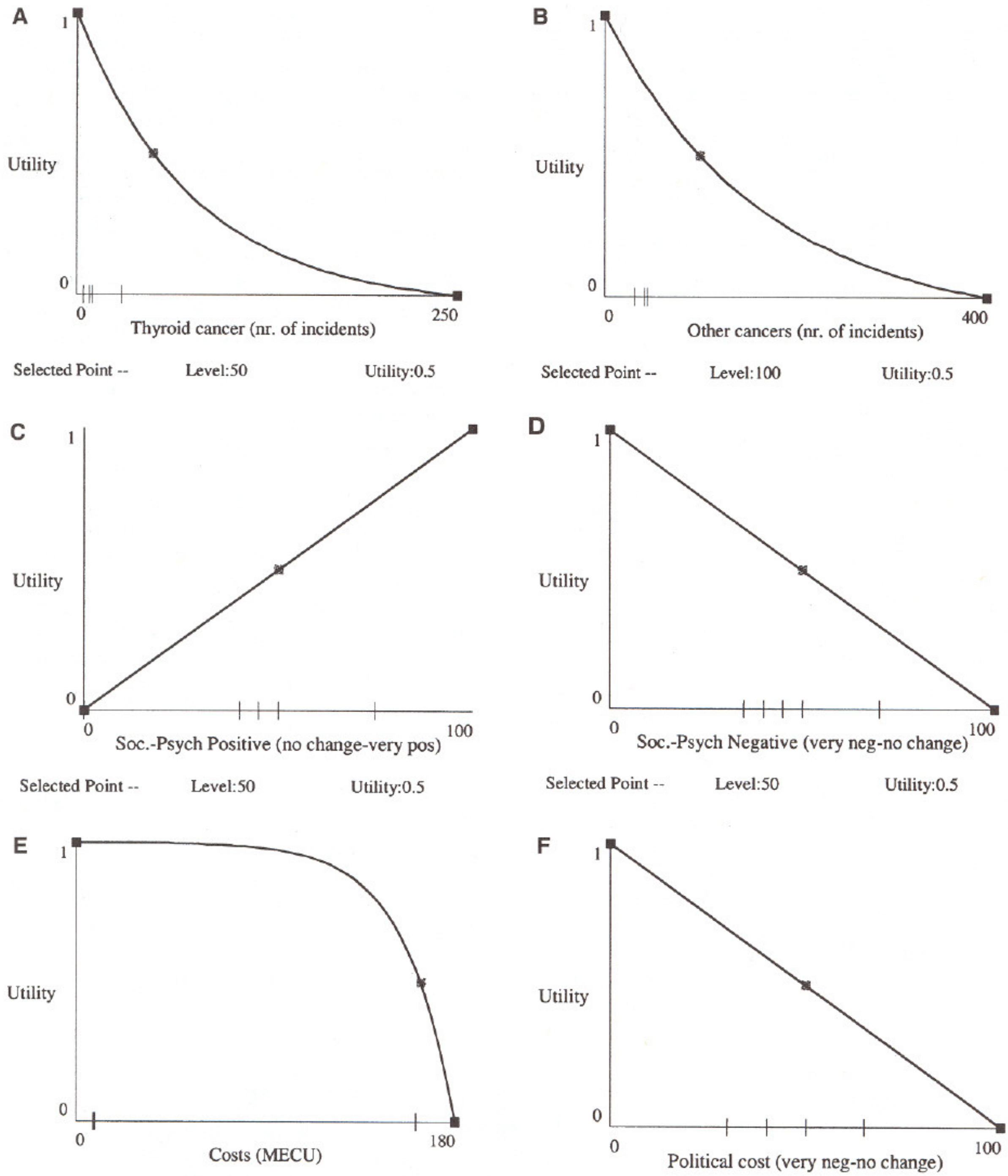

Fig. 4. Utility functions for the different attributes in the second phase of the decision conferences. (A) Thyroid cancer, (B) other cancers, (C) positive effects, (D) negative effects, (E) costs, and (F) political cost.

area where the plume hits after passing the city of Rauma. In addition, iodine prophylaxis is very cheap; no additional costs occur in the model when iodine is administered to over 1 million people (Strategy 3), instead of only 40,000 (Strategy 1).

This type of situation might easily occur when the range of possible countermeasure strategies is wide. Then the worst options will be screened out, but the analysis will have difficulties in discriminating between the remaining choices. One solution could

Table III. The Weights Given in the Second Decision Conference

Attribute	Worst level	Best level	SMART	Trade-off	SMART 95%
Thyroid cancer	240	0 (20)	0.33	0.21	0.40
Other cancers	320	0 (204)	0.26	0.10	0.12
Positive effects	0	100	0.03	0.03	0.04
Negative effects	100	0	0.10	0.10	0.08
Costs	180	0 (30)	0.03	0.05	0.04
Political cost	100	0	0.26	0.50	0.32

Note: The values given in parenthesis and in the last column refer to an elicitation where only the pessimistic scenario was considered.

be to use an iterative process. That is, a rough analysis first screens out the worst alternatives, and then a refined analysis looks more closely at the remaining strategy candidates. This idea will be adopted in future versions of RODOS.[2]

6. DISCUSSION

As previously mentioned, this case study showed that multiattribute risk analysis can improve decision making in nuclear emergency management. However, this approach was novel to many of the participants, and more training is needed to familiarize the decision makers with these tools. One of the conclusions is that, when using multiattribute risk analysis in nuclear emergency management, there must be sufficient understanding of the decision-modeling literature to avoid behavioral and procedural biases.

Decision conferencing is certainly useful in the later phases of an accident, when there is time to model the situation.[5,6,29] Then, the possibility for all stakeholders to learn and take part in the decision process is higher. By contrast, the specific decision conferencing approach evaluated in this study is meant to be adopted in the early phases of an accident. Since time is limited at that point, a common understanding and acceptance of the decision analysis procedures is a prerequisite. All in all, the results from this study are promising. However, further practice meetings must be organized to deepen insight into the features of the decision-making process in the early phases of an accident, and to familiarize decision makers with decision analysis techniques. The positive results obtained in the present study encourage continued research on how to implement decision conferencing in nuclear emergency management.

A current trend in decision support is to make more extensive use of the Internet. In the RODOS project, discussions have been held about using the web to transmit data, and to connect geographically isolated experts and decision makers. In a similar way, decision analysis could be performed using certain software[30,31] and the Internet. The Web could also be used to provide decision makers with other types of support: access to data banks, video footage of the accident, etc. As an example, real-time images from the affected population centers could show how the populace is reacting to the crisis. This information could then be used when deciding on countermeasures, and thus help to ensure a more appropriate response. The information could also be linked to the web-based decision analysis software and utilized online in the decision conference.

It should also be mentioned that this type of setting assumes a single decision stage. In reality, as was pointed out during the conferences, decisions could often be made in a sequential manner: first, warn the public; wait to discover how serious the accident is; and then, if necessary, employ stricter countermeasures. This type of approach was not followed here, but should be considered and tested in the future.

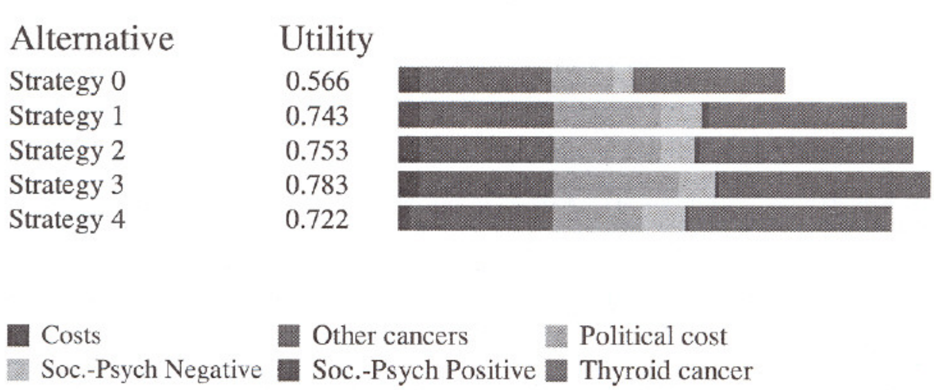

Fig. 5. Ranking of strategies with SMART.

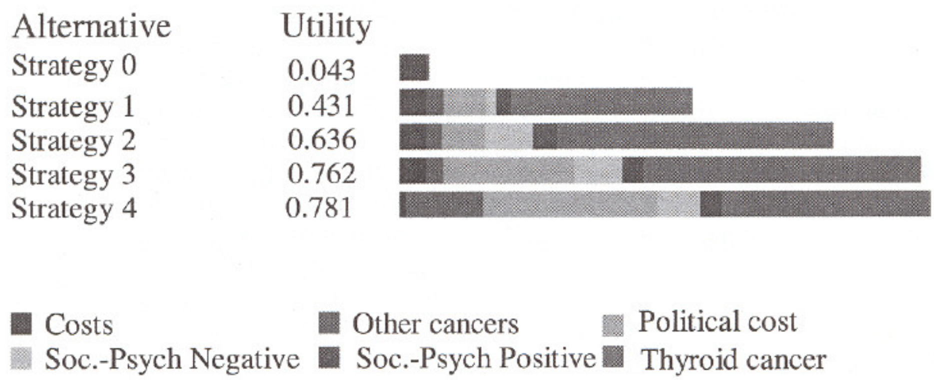

Fig. 6. Ranking of strategies for the 95% fractile case.

The participants unanimously felt that being able to explain and justify decisions afterward is important. The majority of the participants said that multiattribute risk analysis provides a transparent decision-making process that can be used for this purpose.

All in all, the findings in this study concur with previous research.[2–7] It can thus be said that decision conferencing, when applied in a customized manner suitable to the case at hand, is a promising approach. (In emergency situations, however, the format cannot be a day-long meeting, which was the original format suggested by Phillips.[29])

6.1. Process of Analysis

The participants felt that having a neutral facilitator was beneficial, both to keep the discussions focused and to ensure that the appropriate steps were taken in the right order to reach a well-founded decision. As not all of the participants were familiar with multiattribute risk analysis, it was also necessary to have an expert facilitator lead the conferences and assist in using the techniques.

The role of decision analysis software is also important. Software can help decision makers visualize the analysis, and can provide graphical sensitivity analyses, e.g., on the effects of changing the attribute weights. An easy-to-use software package can help the decision maker through the decision analysis phases, but it also limits flexibility and imposes assumptions and simplifications that can lead to nonoptimal decisions. Thus, it is important to understand the methodology used by the software as well as its limitations. At several times in the conferences, the software used was not able to provide the type of approach or output requested. The possibility to quickly conduct what-if analyses would have been especially valuable.

In the early phases of an accident, decisions must be taken quickly. This means that the procedures for making the decision must be fast and focused. Especially when there is so little time available, the procedures must be closely adapted to the intended user. Unfamiliar or nonrelevant procedures are not likely to be followed under times of stress. No matter what features are designed into a system, the users will either adapt the system to their needs, or else resist or even refuse to use the system if it does not meet their expectations and demands.[32–34]

In addition, there are also official regulations and procedures that must be followed (see section 2). Certain adjustments will therefore have to be made to standard multiattribute risk analysis methodology in order to customize it to the requirements of nuclear emergency management. As in previous studies,[6–7] it was noted that a thorough understanding of the decision-making process and the parties involved is essential, and more research is needed in this area.

6.2. Modeling the Decision Problem

Throughout the conferences, a great deal of time was spent on defining factors and terminology. There is a clear need to define the attributes in advance, so that the persons involved understand their correct and intended meanings. Some of the attributes used in this analysis were too vague. For example, the distinction between the sociopsychological attribute and the political cost attribute was not clear. This became even more evident when the impacts were to be evaluated.

There should also be a clear understanding of the appropriate countermeasures to be implemented. Issuing iodine tablets was a component in the strategy, but to whom should they be given? Should the tablets be taken only by children, and will adults comply this with recommendation? In Finland, larger residential dwellings are obliged to store iodine tablets, and small households are encouraged to purchase them. In a real situation, however, not all people may find them, and the effectiveness of iodine prophylaxis could therefore turn out to be quite low. Further examination is needed of other countermeasures and their feasibility.

All in all, the conferences showed how vital it is to have a clear and common framework for discussing the societal aspects of the problem. Explicitly defining the attributes, alternatives, and other factors reveals where there might be problems in understanding, and what is still missing. The participants felt that the multiattibute risk analysis approach helped them to communicate with one another and to include all opinions in the process.

Reality checks should be performed to see whether the results make sense. In nuclear emergency management, there are internationally accepted generic intervention levels to which possible countermeasures can be compared.[26] In addition, there are also suggested values for the relationship between costs and averted population dose.

The utility functions constructed in this exercise are problematic. The participants did not seem to fully understand the elicitation process, and it is not clear how well the functions capture their true risk attitudes. Overall, the handling of uncertainties is still an open issue. Should utility functions, scenario analyses, or some other approach be used? If fractiles are considered, which ones should be included? The concept of probability is also not straightforward. Presenting and handling uncertainties is thus an issue that needs more research, a conclusion also reached in previous studies.[2,6] Ongoing and future research[10] in the RODOS project will address this issue in more detail.

In the second phase of the decision conferences, uncertainties were included and studied. The general finding was that evaluating uncertainties is difficult, and that the incorporation of probabilities is problematic. In the conference, there was a tendency to ignore the other scenarios and concentrate only on the 95% fractile, which was probably due to the fact that the participants were not able to assess all the fractiles simultaneously. The participants were not familiar with utility theory, and were thus not able to use it with confidence. These findings are similar to those of earlier conferences.[2] However, the participants did feel that it is important to consider the risks explicitly, and that the multiattribute risk analysis approach provides a useful framework in this context.

The value tree was fairly easily constructed. An agreement was quickly reached on the factors to be included and those to be eliminated. One can argue that this was partially due to the relatively strong leadership of the experienced facilitator. The preliminary value tree acted as a guide for finding a suitable final version. However, when comparing the value trees used in the different exercises, it can be seen that they changed from exercise to exercise. This is only partly due to the fact that different value trees were needed for different scenarios, it is also an indication that the choice of attributes was not always obvious. More research is needed to determine which attributes to include in the initial tree, and how a generic tree can be constructed. At this point, it should be remembered that the format of the value tree can have an effect on the weights. In studies where an evaluation of nuclear waste disposal sites was conducted,[35–37] varying the value tree affected the weights.

ACKNOWLEDGMENT

This work has been carried out with the support of the European Commission, Radiation Protection Research Action (DGXII-F-6), Contract FI4P-CT96-0053. The RODOS system is being developed by a consortium of nearly 40 institutes from across Europe; see http://www.rodos.fzk.de/. The views expressed in this article are those of the authors and do not necessarily represent those of the RODOS project consortium.

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RODOS: DECISION SUPPORT FOR NUCLEAR EMERGENCIES

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Abstract: In the thirteen years that have elapsed since the Chernobyl accident, many studies and developments have been made with the aim of improving our response to any future accident. One project has been the development of a decision support system to aid emergency management. RODOS, a Real time Online DecisiOn Support system for nuclear emergency management, has been built by a consortium of many institutes across Europe and the CIS. As it approaches (standby!) operational use, we face the task of tailoring the output to meet the specific needs of users and simultaneously opening up their minds to full potential of a modern decision support system (DSS). This paper reports a number of investigations into the decision support needs of the competent national safety authorities and reflects on the implications of RODOS for the emergency management process.

Keywords: Bayesian decision analysis; constraint satisfaction; decision support systems; emergency management; explanation systems; multi-attribute value and utility; RODOS;

INTRODUCTION

One of the lessons to be drawn from the Chernobyl accident was the importance of a coherent, harmonised and sensitive response to nuclear emergencies. Inconsistent responses from a variety of decision making bodies, regional, national and international – even if each is individually rational – confuses the public, leads to poor or ineffective implementation of countermeasures and raises the stress levels in the population, which can of itself cause health effects and increased morbidity [11]. A mechanism for achieving broad consistency of approach is the development and widespread installation of a common, comprehensive decision support system (DSS) for off-site emergency management. The RODOS system (Real time Online DecisiOn Support) has been developed with this as its primary goal. Funded in part by the EU Framework R&D programmes, RODOS is being developed by a consortium of more 40 than EU, Eastern European and CIS Institutes.

The objectives of the RODOS project are:

S.H. Zanakis et al. (eds.), Decision Making: Recent Developments and Worldwide Applications, 381–395.

- to develop a comprehensive and integrated decision support system that is generally applicable across Europe;
- to provide a common platform or framework for incorporating the best features of existing DSS and future developments;
- to provide greater transparency in the decision process as one input to improving public understanding and acceptance of off-site emergency measures;
- to facilitate improved communication between countries of monitoring data, predictions of consequences, etc., in the event of any future accident;
- to promote, through the development and use of the system, a more coherent, consistent and harmonised response to any future accident that may affect Europe.

The RODOS system itself addresses the first, second and, in part, the third objectives; it also provides the platform and databases to act as hubs in an international network set up to facilitate data exchange. The project – together with the many interactions which it has catalysed between experts, organisations and government bodies throughout Europe – has in large measure addressed the third and fifth objectives.

Specifically, RODOS is designed to fulfil a number of roles, the more important of which are:

- a core DSS to be integrated into emergency arrangements at local, regional, national or supra-national levels;
- a stand alone interactive training tool for use, among other things, by those responsible for making decisions on off-site emergency management and their technical advisers at local, regional, national and supra-national levels;
- a more general interactive training and educational tool for radiation protection, nuclear safety and emergency planning personnel with professional interests in or responsibility for off-site emergency management;
- a demonstrator to provide governments and their agencies with a view of the state of the art in emergency management DSS;
- a research and development tool to explore the merits and limitations of new techniques or approaches before their more formal integration into operational decision support systems;
- a more effective means for communication and exchange between countries of information such as monitoring data and prognoses of accident consequences.

Its development has also contributed to the improvement of existing emergency management DSS's through the development and dissemination of improved stand-alone modules.

The roles for which RODOS is designed largely determine its potential users. These include those responsible at local, regional, national and supra-national levels for off-site emergency management and related training, for the operation of nuclear installations, for public information, or for communication and exchange of information (e.g., in accord with bilateral or international agreements); the research and development community concerned with improving decision support for off-site emergency management; and developers of decision support systems for the management of non-nuclear emergencies.

The system has been designed in a modular way so that its functionality can be tailored to each user's particular needs.

Background material on decision support for nuclear emergencies can be found in the conference proceedings [11], [12] and the references contained therein. Earlier descriptions of the RODOS system may be found in [2], [7]. This paper concentrates on aspects of the interaction between the users and the system. As we shall indicate, in the past these have not received as much attention as they deserve.

THE RANGE OF SUPPORT PROVIDED

RODOS is designed to support decision makers throughout all phases of a nuclear accident. The early versions of RODOS supported the decision making during the early stages of a release (2-3 days) for regions up to about 30km. from the plant. The current version extends the support to considerably longer ranges: indeed, the atmospheric dispersion chain can predict on European scales and the hydrological models can deal with river systems such as the Rhine basin. Countermeasures such as food bans running months and years into the future can be examined. By late 1999, the support will be truly comprehensive and for all time periods, supporting decision making at all ranges on countermeasures ranging from immediate evacuation through food bans and agricultural changes to permanent relocation.

RODOS needs to support a variety of DMs beginning with the plant or site managers and local emergency management teams who will have responsibility for countermeasures in the early hours of an accident. Their decision making is constrained by national and international intervention levels as well as many other pre-planned rules developed during emergency exercises. Their thinking will be primarily related to health and feasibility issues and have little to do with political, economic or social criteria. But later, when regional, national and international politicians become involved, the full range of criteria will become relevant. There will be little opportunity to deploy pre-planned countermeasure strategies, since specific aspects of the context will dominate the determination of appropriate countermeasures.

Of course, RODOS will not be 'driven' by the DMs themselves. Environmental scientists, meteorologists, public health, civil servants and other advisors will run modules and interpret the output in discussion with the DMs. Nonetheless, the graphical, tabular and numerical output should be understandable by the DMs; it is likely that it will be projected onto screens before them in a decision support room.

RODOS seeks to provide decision support at all levels ranging from largely descriptive reports to a detailed evaluation of the benefits and disadvantages of various countermeasure strategies and their ranking according to the societal preferences as perceived by the DMs: see Figure 1. Support at levels 0, 1 and 2 comprises the provision of information to DMs. Thus, data are organised within RODOS to provide maps of the predicted, possible and, later, actual spread of contamination and predictions of the effects of countermeasures. The system is able to perform 'what-if' calculations, allowing investigation of how the situation may develop. Level 3 support focuses on evaluation and thus explicitly seeks to model the DMs' judgements. It involves the use of techniques of prescriptive decision support based upon multi-attribute value and utility (MAV/U) models.

Level 0:	Acquisition, checking and presentation of radiological data, directly or with minimal analysis, to DMs, along with geographic and demographic information.
Level 1:	Analysis and prediction of the current and future radiological situation based upon monitoring and meteorological data and models.
Level 2:	Simulation of potential countermeasures, e.g. sheltering, evacuation, issue of iodine tablets, food bans, and relocation; determination of their feasibility and quantification of their benefits and disadvantages.
Level 3:	Evaluation and ranking of alternative countermeasure strategies in the face of uncertainty by balancing their respective benefits and disadvantages.

Figure 1. Levels of decision support provided by RODOS

Emergencies involve uncertainty. There are many unknowns, many sources of error: scale of the release, accuracy of radiation monitoring data, weather conditions, the reliability of expert judgement, the success in implementing countermeasures, and the accuracy of the many mathematical models used. During the progression of the accident many data sets will arrive from different sources and of varying accuracy. The design of RODOS addresses all issues relating to uncertainty and data assimilation in a coherent fashion[7]. Bayesian methods are to be used throughout in which all uncertainties are modelled using probabilistic methods and in ways that are compatible with the evaluation of the alternative countermeasures by means of MAV/U models: see Figure 2. This methodology separates scientific issues in understanding data and resolving uncertainty from issues of value judgement which belong to the realm of the political DMs: see [8]. By 1999 some uncertainty handling and data assimilation will be included in the modules, but work on this is ongoing both because of the need to develop the deterministic meteorological, environmental and health models first and because the task is a substantial one.

Among DSS's developed for use in the context of nuclear emergencies, RODOS is unique in its comprehensiveness, its approach to data assimilation and uncertainty handling and its ability to provide level 3 support.

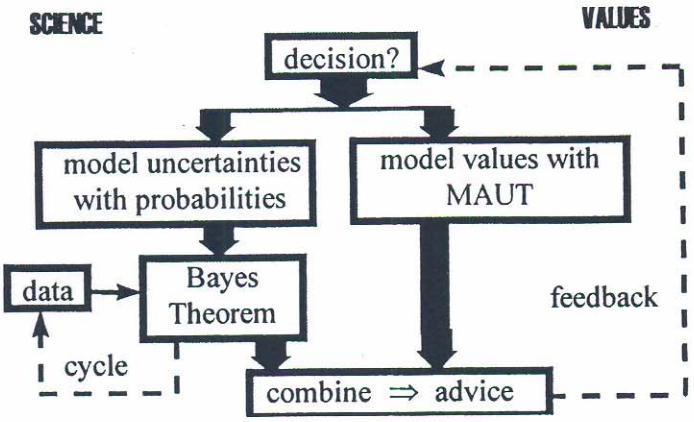

Figure 2. Bayesian methodology

THE RODOS SYSTEM

The conceptual architecture of RODOS consists of three types of subsystem:

- Analysing Subsystem (ASY) modules process incoming data and forecast the location and quantity of contamination including temporal variation.
- Countermeasure Subsystem (CSY) modules suggest possible countermeasures, check them for feasibility, and calculate their expected benefit in terms of a number of attributes (criteria).
- Evaluation Subsystem (ESY) modules rank countermeasure strategies according to their potential benefit and preference judgements provided by the DMs.

The development of ASY and CSY modules to predict, in a timely and computationally efficient manner, the spread of contamination, its likely effects and the scale of mitigation offered by possible countermeasures is a major scientific achievement of the RODOS project. Not only have new models been developed and old ones modified, but all have been integrated into a common system, sharing data and passing information seamlessly from one to another. For instance, the meteorological chain gathers together local and European scale weather forecasts, runs a local scale puff model to predict dispersion and deposition over a few tens of kilometres and then hands the task over to a long scale particle model to continue the predictions to hundreds and thousands of kilometres. Similarly, there are several hydrological models which combine together to predict dispersion through run-off, river and lake systems and shortly marine systems. Deposition data, either from prediction or from actual measurements on the ground can be fed into long term food chain and health models to predict long term population and livestock effects.

Each phase of a nuclear accident is distinct in countermeasures open to the DMs, the urgency with which they must be implemented and the forms, accuracy and quantity of data available. RODOS must recognise this temporal context in order to provide support during all phases. As time passes, RODOS will arrive at different decision points where it must select modules to form an ASY–CSY–ESY chain appropriate to the context of the decision. The time intervals between two decision points may be a matter of minutes or hours early in an emergency situation and longer – days or weeks – at later phases.

A sophisticated control subsystem lies at the heart of RODOS. This manipulates modules, building appropriate ASY–CSY–ESY chains in response to user requests or some pre-programmed sequence of desired analyses. It provides the flexibility within RODOS to change its operating behaviour according to the current phase of the accident. It monitors and controls all data input the rules used to manipulate them. Whenever RODOS receives data or input, it is able to re-examine and re-evaluate whether more detailed analyses are possible or necessary. RODOS also needs to be able to cope with data arriving out of sequence relative to their times of observation.

RODOS is a real-time, on-line system connected to meteorological and radiological data networks. Thus there are communication modules. Its database formats are defining the basis for designing data exchange on an European scale, with RODOS systems acting as hubs in the network.

Underpinning the whole user interface is a sophisticated geographic information system (GIS), which displays both demographic, topographic, economic and agricultural data along with contours of radiological data or predictions: see Figure 3. These displays seek to ensure that the output can be used and understood by the variety of users who may possess qualitatively different skills and perspectives.

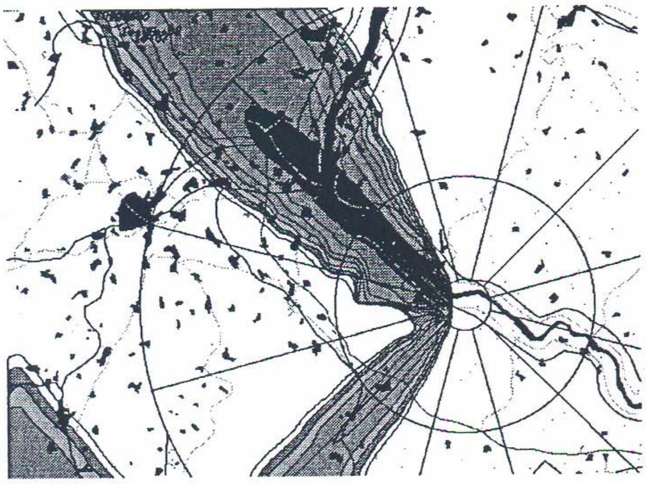

Figure 3. Part of the GIS showing the paths of two plumes, one the result of a second release some hours after the first after a change in wind direction.

RODOS operates in either a semi-automatic or an interactive mode. In the early phases of an emergency, monitoring data and expert judgement will be entered into the system. The system offers the facility to present all the relevant information for decision making automatically according to pre-agreed rules developed during exercises. Relying on interactive control would be inappropriate because of the urgency during the early hours of an accident. In later phases, operation will be more interactive and reflective, seeking value judgements from the DMs and indicating the consequences of these. At all stages there will be automatic checks on the quality of the models such that if the predictions depart significantly from incoming data, warnings will be issued to the user.

The modular design of RODOS recognises client-server design so that the system may be distributed across a network of computers. The interface has been built using standard X-windows for Unix, and the modules written in ANSI C, C++ or Fortran.

Further details of the system and the range of models employed in the ASY and CSY subsystems may be found in [2] and the references therein. We concentrate here on the ESY.

THE EVALUATION SUBSYSTEM

The first component of the ESY (Figure 4) is a knowledge-based system which we call coarse expert system [16] that generates feasible alternatives. In a nuclear emergency, there are several countermeasures such as evacuation, sheltering or food bans that can be applied to the areas around the nuclear plant. The number of alternative strategies i.e. combinations of countermeasures can be very large. However, not all of these strategies are worthy of further evaluation. Some strategies may be infeasible or do not follow some practicality rules. For example, there might be some temporal constraints that do not allow issuing iodine tablets to people who have already been evacuated. There are also some rules determined by international and national radiation protection bodies which strongly advice intervention in some specific circumstances. The knowledge-based system encodes these rules and constraints and discards those strategies that do not satisfy them.

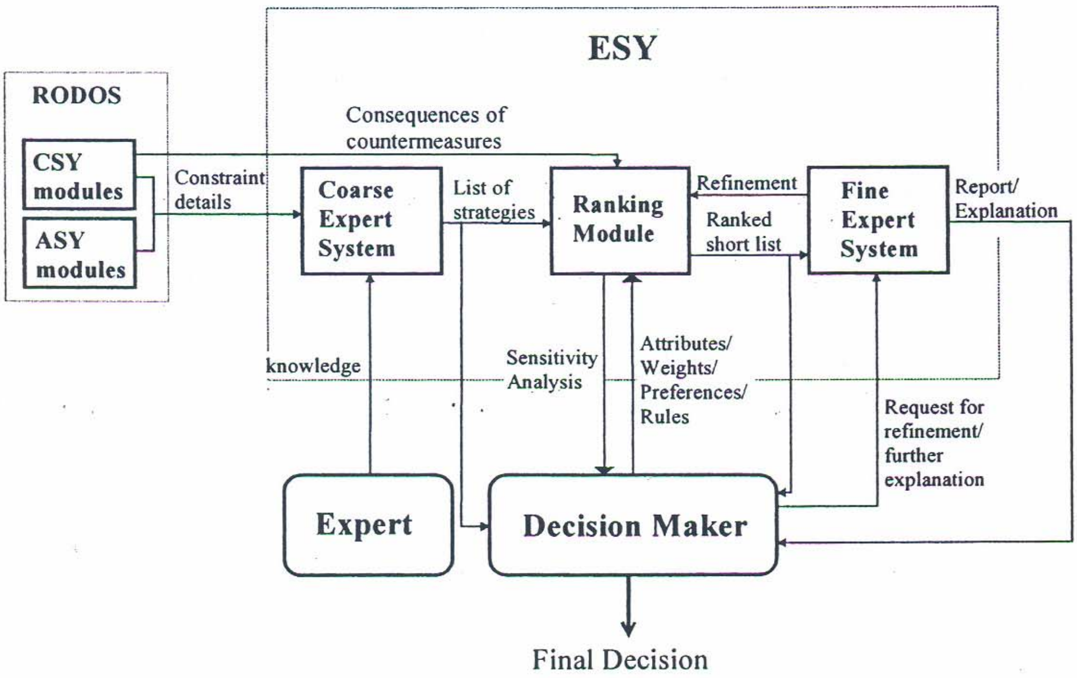

Figure 4. The ESY module

The second component of the ESY is a ranking module that evaluates and ranks the alternative strategies based on their consequences and the preferences of the DMs [3], [17]. A multi-attribute additive function is currently used for the ranking of the strategies. Other forms of utility functions that model the inherent uncertainties in a nuclear emergency are being considered. Several modules in RODOS assess the consequences of the strategies on the different attributes being considered; e.g. the EMERSIM, ECONOM and HEALTH modules [18] calculate the consequences of early-phase combinations of countermeasures such as evacuation, sheltering and issue of iodine tablets and the LCMT-FRODO [1] module estimates the effect of agricultural countermeasures such as disposal and process of food. Pareto plots are presented as well as sensitivity analysis graphs to illustrate the effect of the weight of an attribute in the ranking of the strategies.

The criteria and their associated attributes taken into account in the evaluation of strategies differ depending on the phase of the nuclear emergency. At the early phases of a nuclear emergency (hours and days after the radiation accident), the DMs are concerned with health effects, the public anxiety which would be caused by the incident and the measures taken, feasibility matters and to a lesser extent cost-related issues. At later phases (months and years after the accident), the DMs will have more time to spend on balancing both the short and long term health effects with the cost of the strategies.

The third component of the ESY is called fine expert system and it provides explanation facilities [14]. Previous studies [20] have shown that the advice of a decision support or expert system is very likely to be rejected if no explanation facilities are provided. In order to add transparency into the way that the alternative strategies are ranked and justify its recommendation, the ESY generates a natural language report explaining why one strategy was preferred over another.

The human-computer interface of the ESY has been evaluated in a number of ways: see [15].

THE DEVELOPMENT OF RODOS

RODOS has been designed almost entirely by scientists and engineers. There has been little user involvement. This is not a criticism, merely a statement of historical fact. Firstly and most importantly, the senior emergency managers – mayors, senior civil servants, politicians, etc. – who are responsible for decisions on emergency management in event of a nuclear accident spend by far the greater part of their time on quite different tasks. They had – and have – little clear perception of their own needs. We shall return to this point below. Secondly, their advisors were not much clearer on how the system should be designed. For, although the management of the Chernobyl Accident in the former Soviet Union and across Europe had indicated a need for much improved information management and support for decision making, there was little consensus on what this should be.

In the early 1990's when the software architecture was primarily designed, only scientists and engineers had a vision of what was technically possible. The growth in information and communication technologies at the time was such that much more detailed forecasting of the evolving situation was possible than was included in the then current emergency management processes. The emergency managers and their close advisors were unaware of what a system such as RODOS could offer and hence could not help in the detailed planning of interfaces and its integration into the emergency management process. Thus the RODOS system was designed by scientists and software engineers, at one remove from the emergency management process, with the intention of stimulating a vision of what was possible and so bringing about more constructive user involvement in the design of later versions.

In the intervening years a variety of modules have been developed for RODOS which enable it to predict and evaluate the consequences of a release, both before and after potential counter measures are taken, from the near to far range and from the short to the long term. This is a considerable accomplishment, and it is one on which we need to build as we take RODOS into operational use, tailoring it to the emergency management process.

EMERGENCY MANAGEMENT PROCESSES

The first point to appreciate is that there is no single agreed structure for the process of emergency management common to all countries and regions across Europe. The process, those involved and their responsibilities vary from country to country and, indeed, sometimes from region to region within country. In some countries there is a single national crisis centre, permanently staffed and responsible for managing any emergency, not just nuclear. In others there are national or regional crisis centres specifically focused on nuclear incidents. In others still, the process is much more devolved with many organisations playing a role. Nonetheless, there are common themes. The decisions which need to be supported are, by and large, the same.

When an accident threatens, plant managers will take engineering actions to avoid or reduce the risk of a release. The first decisions on protecting the public – and the first to be explicitly supported by RODOS – would be whether to take precautionary measures such as: issuing a warning, distribution of iodine tablets, and starting to evacuate some areas. If there is a release, decisions will be needed on advice to take iodine tablets, and on sheltering, and evacuation. The following days will see decisions on measures such as food bans, decontamination of livestock, agricultural produce and properties, and restrictions on business, leisure activities and access to the region. After several days or maybe weeks, there will be a need to consider longer term measures, e.g. permanent relocation (resettlement) and permanent changes to agricultural practice and local industry.

Here we focus myopically on the needs of DMs in relation to the support of *their* judgements and decision making. We do not directly address their informational requirements in relation to the outputs of dispersion models, ground contamination models, etc. RODOS seeks to provide judgemental support via Bayesian multi-attribute decision models: see [3], [8].

DECISION SUPPORT NEEDS IN THE MEDIUM AND LONG TERM

Given that most emergency exercises concern the decisions to be taken in the early phase, it is perhaps surprising that we have a much clearer idea of the needs of DMs in the medium and long term in relation to decontamination and clean up, changes in agricultural practice, relocation, etc. Although for these many of the issues are less structured than in the earlier phases, the time pressures are sufficiently less for decision models to be built or, at least, modified and tailored at the time. Uncertainty is less of an issue, because, although the health effects due to the radiation will be stochastic in the sense that we will not know *who* will get cancer, the uncertainty about *how many* will is much smaller. Moreover, we have a number of studies relating to the Chernobyl Accident [11], [13] and to carefully structured exercises [9] which show that multi-attribute value methods provide a powerful and effective form of modelling to help the DMs explore, understand and communicate the issues which drive their decision making. Indeed, some promote the use of these methods to enable various organisations and stakeholders to participate in these decisions. Thus for decision making in the later phases, we are relatively confident that the evaluation modules that we have designed and implemented are able to meet DM needs. Such is not so clearly the case for the early phase.

DECISION SUPPORT NEEDS IN THE THREAT AND EARLY TERM

In an attempt to understand better the needs of DMs in handling the early stages of a nuclear emergency we have run two series of exercises. In the first series held in 1994 to 1996, we ran five exercises: two in Germany, and one each in Belgium, France and the UK. The events were attended by the officials and their advisors who would be responsible for deciding upon and implementing emergency measures in their areas. The scenarios used focused on a threat of a release. There had been a failure in part of the reactor and the probability of a release was set at 10% (i.e. there was a 90% chance that engineering efforts would avert a release). To complicate matters the wind was swinging and the path of the plume could not be predicted with accuracy. We told the DMs that if the release *did* occur there was a 50:50 chance of the plume passing entirely over rural communities, who could easily be evacuated or over a densely populated city whose inhabitants could not be evacuated. See Figure 5. In each exercise, we created this scenario in the context of a real nuclear plant in the DMs' area.

The conclusions drawn from these five exercises were:

- The DMs generally found the presentation of data and predictions very useful: i.e. our level 0, 1 and 2 support was a success. Indeed, the interactive support simply provided by a geographic information system was novel and thought to be valuable in itself. 'What-if' analyses were used extensively. However, judgemental support (level 3) was not sought and the facilitators running the exercise were unable through discussion to convince the DMs otherwise. They felt able to make the decisions required of them without detailed modelling and exploration of their value judgements.

- In relation to the specific issue of building a multi-attribute model, no group were able to articulate an explicit set of criteria upon which they based their decision making. They did not find it natural to think in terms of the multi-attribute models. *Anticipated regret* seemed to be a major driver in their decision making. French *et al.* [5] propose event conditional modelling to address this issue.
- The introduction of uncertainty into an exercise was very discomforting to the DMs. None found the expression of this uncertainty in terms of probabilities useful. Generally, they adopted the heuristic of assuming that all the area at risk would be exposed: i.e. they effectively assumed a much larger and broader plume than would be formed by any possible release.
- Issues relating to the equity of treatment of different sub-populations were of considerable concern. Was it right to evacuate rural regions when it was quite infeasible to evacuate a highly populated urban region which was equally at risk in terms of individual dose? No consensus emerged on this issue. The matter is further discussed in [4].
- The issue of communicating with the public was discussed at length in all three exercises. All groups expressed concern that the communication of the risks should not raise stress levels unnecessarily. All felt need of advice on how to word press releases and other announcements so as to achieve their desired end. See [6] and [19] for discussion of some of the methods that might be employed.

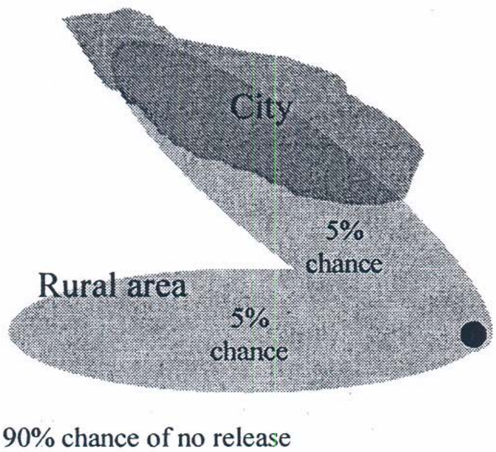

Figure 5. The situation during the threat phase of the first series of exercises

A distinctive point of these exercises was that we rehearsed a threat. This is contrary to practice in most practice exercises: a fact which concerns us. Resource constraints and the need to exercise as many aspects of the emergency arrangements as possible mean that most exercises assume the release of significant amounts of radioactivity. This does not accord with reality: most 'trips' at reactors do not lead to a release, but may set in motion the emergency management process. There is, thus, a distinct possibility that DMs are, through their training, being conditioned, albeit inadvertently, to believe the worst will happen. The implications for the future training and exercising of DMs warrant further analysis and evaluation. One means of overcoming such difficulties would be to involve DMs in more limited (and perhaps more frequent) table top exercises for which RODOS could readily provide the requisite input, analysis and evaluation in real (or artificial/contrived) timescales.

A second series of exercises have been run between 1997 and 1999. Some of the results are still being evaluated, but they have added greatly to our understanding of DM needs. These exercises were led by individuals and groups who had hitherto played no or little role in the design of RODOS. They are reported in [10] and a series of papers referred to therein. The scenario underlying these exercises was based on a LOCA accident followed by containment failure at nuclear power plant in Finland. All data were realistic, even though the chances of such an accident are estimated at less than 1 in 100 000 per reactor-year. An initial release of radionuclides was assumed, thus removing the issue to do with the *threat* of any release. This was done because it was felt that the first exercises had shown that uncertainty is so dominant an issue that other matters may be obscured: perhaps we had failed to build attribute trees because of the difficulty the DMs had in conceptualising the uncertainty relating to the threat.

After a number of iterations an attribute tree was built successfully: see Figure 6. It is interesting to note that this tree has a very similar structure to those developed in the Chernobyl studies and medium and long term exercises [9], [13]. One difficulty was in separating issues to do with social-psychological impacts from political ones. It is also interesting that economic costs were perceived as a factor in evaluating countermeasure strategies. In the earlier exercises this had been less clear. Cost was not perceived to be an issue in the early phase: at least is was not with one qualification. In one exercise it was noted during the threat phase, that if the accident happened funds would be made available from contingency provisions. If it did not, the costs of precautionary measures would fall on the already stretched normal operating budgets of the emergency services.

Although the scenario used excluded uncertainty relating to the threat, in a second run of the exercise there was uncertainty relating to the scale of the source term, i.e. how much was released. The tree used was modified from Figure 6, but shared the same generic structure. The facilitators were successful in building a multi-attribute utility model to reflect and support the DMs judgements in dealing with this uncertainty. However, because of the short time available to build the utility model, the facilitators were not confident that the DMs had a full understanding of its import. None the less, there is preliminary evidence here that once the threat issue is removed from the scenario, Bayesian multi-attribute decision analysis does offer a structure in which to analyse and support judgements.

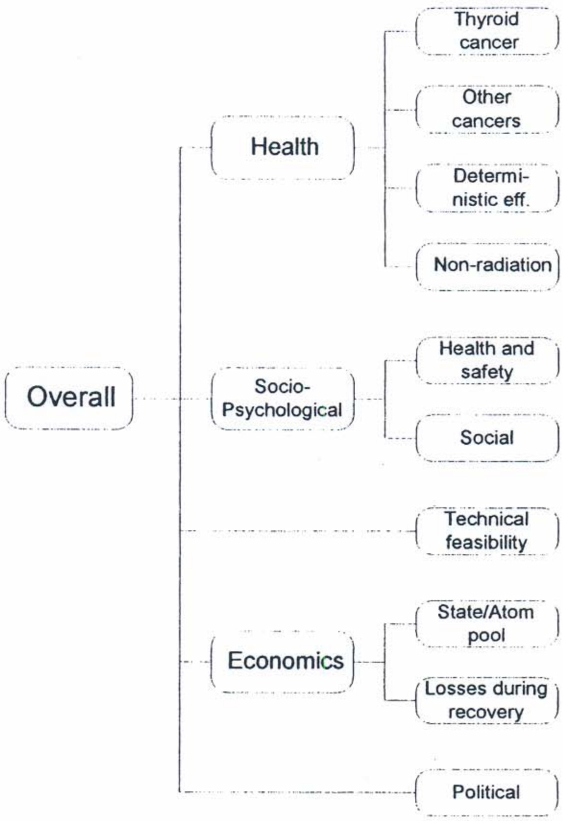

Figure 6. Final attribute tree built in the Finnish exercises

Again there was some evidence that the DMs faced up to uncertainty using conservative heuristics. They concentrated attention on the effects at the 95th percentile of the source term distribution: i.e. the worst case. While there is a *prime facie* case that such a conservative perspective provides the best protection for the public, it is not a foregone conclusion that it does. There are social and psychological costs, and potential health costs in addition to economic ones from implementing unnecessary countermeasures.

DESIGN OF THE PROCESS OF EMERGENCY MANAGEMENT

The advent of DSSs such as RODOS with their potential to support more detailed analyses and 'what-if' simulations mean that the emergency management structures in some countries or organisations might need revision to allow more interaction between technical experts and DMs. Indeed, it may be wise to reflect more widely on the structure of the process. As already noted, it varies from country to country and the differences in organisation are so great that we find it difficult to believe that all are equally effective. Some investigation and comparisons in order to develop international advice on the structure of the emergency management process would seem to be required.

CONCLUDING REMARKS

The design of RODOS has had to tread a difficult path between meeting the needs of users as they perceive them and opening up their minds to the possibilities that modern powerful DSSs provide. It is for others to judge whether we have negotiated this path successfully – so far. We recognise that for a variety of historic reasons, the early development of RODOS was influenced primarily by scientists and technologists. Recently, however, we have been able to investigate user needs more fully. What is clear is that there is much still to be done in shaping emergency management and its support to be better able to cope with nuclear accidents.

ACKNOWLEDGEMENTS

The RODOS system has been developed by many hundred individuals working in many institutions: see http:\\resy.fzk.de\rodos. As authors we report their work but do not claim it. Nonetheless, we take responsibility for any errors. Moreover, the views expressed are our own and not necessarily those of the project as a whole or any of the associated institutions. The development of RODOS has been funded from many sources, but particularly the EU Framework R&D programmes, all of which we gratefully acknowledge.

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Decision Conferencing on Countermeasures after a Large Nuclear Accident

Risø-R-676(EN)

Report of an Exercise by the BER-3 of the NKS BER Programme

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January 1993

Abstract The BER-3 Project of the emergency preparedness programme (BER) of the Nordic Co-operation Organisation (NKS) organised a decision conference to address the following objectives.

1. To achieve a common understanding between decision makers and local government officials on the one hand and the radiation protection community on the other of the issues that arise in decisions in the aftermath of a major nuclear accident.
2. To identify issues which need to be considered in preparing guidance on intervention levels.
3. To explore the use of decision conferencing as a format for major decision making.

To achieve these objectives the participants were invited to consider a scenario of a hypothetical radiation accident. The scenario assumed that appropriate early protective actions (sheltering, issuing of iodine tablets, etc.) had been taken and that the conference was meeting some eight days into the accident to consider medium and longer term protective actions, particularly the need for relocation of certain areas. By the end of the conference, considerable consensus on the general form of the strategy had emerged. Moreover, there was a better understanding of the evaluation criteria against which such a strategy needed to be developed.

Many felt that it was important to retain flexibility in the strategy of protective actions, even if this increased the uncertainty for the affected population, who would not know exactly what would be done for several months. This emphasised even more the need for good communication and understandable presentations of the adopted strategy. All felt that more research and advice is needed on the psychological effects of such accidents and the effects of protective actions. It was felt that the exercise had illustrated the problems inherent in radiation emergencies. However, a different situation with larger populations could have led to different results.

It was agreed that the exercise had been useful in meeting the need to think about the issues before an accident happens. On the general matter of intervention levels, it was suggested that guidance should not constrain the authorities into doing something which might not be appropriate to the particular circumstances of an accident. It needed to recognise, for instance, that one can evacuate small numbers of people but not large cities.

ISBN 87-550-1887-4
ISSN 0106-2840

Grafisk Service, Risø, 1993

Contents

1 Introduction

The BER-3 Project of the emergency preparedness programme (BER) of the Nordic Co-operation Organisation (NKS) Programme organised a *decision conference*[1] on December 8th-9th, 1992 at the Civil Defence High School at Snekkersten, Denmark. The objectives of the conference were threefold:

1. To achieve a common understanding between decision makers and local government officials on the one hand and the radiation protection community on the other of the issues that arise in decisions in the aftermath of a major nuclear accident.
2. To identify issues which need to be considered in preparing guidance on intervention levels.
3. To explore the use of decision conferencing as a format for major decision making.

To achieve these objectives several local government officials, emergency planners and members of the radiation protection community in the Nordic countries (A list of participants is given at Annex 1) were invited to consider a scenario of a hypothetical radiation accident. This was developed from one in the BER-3.2 Report. The accident was assumed to have happened on December 1st, 1992 and had left the North of the island of Gotland significantly contaminated, caused by a heavy snowfall during the plume passage. Appropriate early protective actions (sheltering, issuing of iodine tablets, etc.) had been taken, and the conference met eight days into the accident to consider medium and longer term protective actions, particularly the need for relocation of certain areas. Every participant had been circulated with a brief description of the first three days of the accident beforehand: see Annex 2. Some - the technical experts who in reality would be much more closely in touch with the detailed situation - were sent a more technical briefing just before the meeting: see Annex 3.

It was realised from the outset that total realism could not be obtained, and many flaws with the form of the exercise and the scenario were noted both before and during the conference. Clearly no papers circulated beforehand could simulate the level of knowledge that each participant would have had in a true emergency. The data were lacking in many respects, particularly in relation to the level of uncertainty that might be expected on some of the measurements and the distributions of dose in both space and time. The response of the public and the media to the emergency had not been simulated in any respect. The conference involved rather more people than would have taken part in a single country's emergency response. Also technical support would have been far greater in practice, with many more modelling and dose prediction programmes available. Because of its exploratory nature, several decisions were taken during the conference to limit the discussion to a few possible relocation strategies, to take on trust certain estimates of cost, to assume that most of the public would adopt the advice given by officials, etc. None the less, within these limitations the participants entered into the conference willingly and gave valuable and realistic opinions and judgements as required. The BER-3 and the conference organisers are grateful to them all for the spirit and the enthusiasm that they showed.

Confidentiality was discussed at the outset. It was agreed that a decision would be made at the end of the conference on what might be reported more widely, but until then all discussion would be confidential. At the end of the second day, all participants agreed that the discussion and the models could be reported, subject to the points made in the preceding paragraph being noted: namely, that no exercise could simulate reality perfectly and that their deliberations had been limited by lack of certain data, etc.

The report is organised as follows. The early sections focus on the discussion and conclusions drawn and thus address the first two objectives of the conference. The concluding section reflects on the nature of decision conferencing and its success or otherwise as a format for running such meetings.

[1] Briefly a decision conference is a two or three day meeting in which a group of decision makers gather to consider major strategic issues. The distinguishing feature of a decision conference is that the decision makers are suppoorted in their deliberation by a *facilitator* and an *analyst*, who do not contribute to the content of the discussion but rather focus their attention on the decision making process, helping the decision makers achieve a shared understanding through the use of decision modelling. Further details are given in Section 6.

2 Concerns and Issues

The conference began with a wide-ranging debate of many of the issues and concerns that the scenario stimulated.

- The word 'acceptable' was used on many occasions: e.g. acceptable risk. Some felt 'tolerable' was a more appropriate word to use in most, if not all circumstances. All felt that what was acceptable or tolerable was to be the subject of the two days' discussion.
- The question of budget was raised. Would the cost of protective actions be a limiting factor? It was felt that the limited scale of the accident would mean that money would be made available for all the protective actions that might be considered and that total cost would not be a constraint, although 'value for money' issues would be of concern. It was pointed out that, had the accident led to parts of Copenhagen being contaminated, the costs would have been far greater due to the greater density of population and total cost would have been a serious issue.
- Time scales: how far into the future should protective actions be planned? Some felt that strategies should look to the next few weeks without making longer term commitments. It was felt strongly by the decision makers that flexibility would be an important attribute of the strategies. Waiting for the snow to melt and determining actual rather than predicted contamination was felt to be important. However, others felt that, firstly, predictions of contamination would be relatively accurate: there was much experience in Scandinavia of predicting contamination after the melting of snow. Secondly, and more importantly to them, the public would be concerned if the protective actions' strategy left too many uncertainties. People would want to know how long they were being evacuated and whether permanent relocation was necessary.
- It was agreed that if any evacuation[2] was for longer than a year, this should be looked upon as permanent relocation.
- Issues related to psychological stress, social and political acceptability and public confidence were discussed many times in the conference. It was acknowledged that psychological stress could lead to health effects of a comparable nature to those arising from the contamination and at the same time reduces the quality of life significantly. Many of the points made in Eränen and Salo (1992) were repeated in the conference.
- All agreed that it was of paramount importance to ensure that communications with the public were clear and that the advice given was both transparent and supported by easily understood reasons. Because of the unanimity on this, the issue of communications was not discussed in detail during the meeting: it was assumed that whatever strategy was adopted, emphasis would be placed on conveying it clearly and understandably to the public.
- There was a need for the short term and longer term protective actions to be consistent. Both for the public to understand the measures and for them to be applied fairly, the different aspects of the strategy must cohere. If public confidence was not maintained, the ability of the authorities to continue to deal with this accident and also to deal with future accidents would be severely reduced. The importance of monitoring the public's attitude towards the authorities handling of events was noted. It was suggested that information on this can be obtained within a week, especially if its collection planned in advance. Thus in a real conference taking place some eight days after an accident it would be possible to have information available on the public's attitudes.
- It was also agreed that no strategy in this scenario would involve compulsion. Only advice, albeit strong advice, would be given by the authorities.
- Once advice had been given the authorities would have to bear the cost of following that advice. Thus in evaluating the strategies, their full cost was assumed to fall on the authorities. It was recognised that in practice cost might be reduced because of non-compliance or because members of the public used their own resources, but no allowance for this was made in the modelling.

[2] The terminology used in the conference is followed in this report. ICRP, for instance, recommend the terminology 'temporary or permanent relocation' for periods in excess of one week.

- It was noted that there would be differences between the compliance with the advice given by young and old families. Those with young children and particularly those who were pregnant would be more likely to relocate. Older families would be more likely to remain whatever the advice. It was also noted that whole families would need to be relocated or evacuated. Moreover, some members of the community would need to relocate if others did: e.g. school teachers, if all the younger families left the region.
- Security would be an issue. If properties were left unoccupied, their security would need maintaining.

3 Development of the Decision Models

During the two days, a sequence of multi-attribute value decision models was built, each refining the perspective brought by the previous one. For a description of the form of such models, see, e.g., French (1986), Lochard, Schneider and French (1992) or Gjørup et al (1992).

The criteria for evaluating possible strategies were discussed upon many occasions. Issues related to social acceptability, psychological stress and the confidence of the population at wide in the authorities were repeatedly considered. The hierarchy of evaluation criteria or attributes given below is that used in the 'final' evaluation on the second afternoon.

Evaluation Criteria

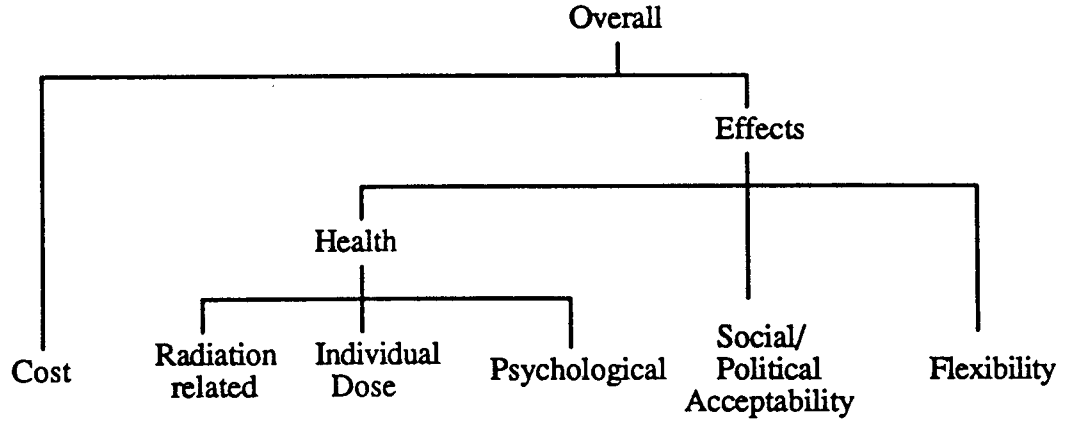

Figure 1: Hierarchy of evaluation criteria used in the final decision model.

The different *evaluation criteria* or *attributes* were defined as follows.

Cost

The cost calculated in MSEK allowing for the cost of relocation per person, the costs of evacuation per person, the cost of lost capital and lost land, and the cost of decontaminating regions.

Health

The effect on health was seen as having three components. The following abreviations were used for these.

Radiation Related Health Effects. Expected number of cancers saved by averting the collective dose, calculated by applying a risk factor of 5% to the dose in manSv (ICRP).

Individual Dose Health Effects. Concerns for the well being of pregnant women and for children as well as for other individuals was expressed through the maximum expected individual dose in the first month if the strategy were applied.

Psychological Health Effects. Loss of quality of life, destruction of social networks, temporary accommodation, radiation fears, increased rates of abortion, voluntary limitation of family size, etc. causing stress, depression, and other clinical effects which might lead to increased morbidity and mortality.

Strategy	Relocate indefinitely	Evacuate for 6 months	Decontaminate while evacuated
1	-		-
2	-	I	I
3	-	I,II	I,II
4	-	I,II,III	I,II,III
5	I	-	-
6	I	II	II
7	I	II,III	II,III
8	-	I,II,III	-

Table 1: The Strategies defined in terms of their effects on areas I, II and III

Social/Political Acceptability

Acceptance of the population and agreement that the authorities have dealt with the situation adequately.

Flexibility

Ability of the authorities to react to the evolving situation. In particular, it was felt that leaving certain decisions about decontamination to the Spring would be particularly advantageous.

Strategies

Seven strategies for protecting the population were considered[3] in the early decision models and an eighth was added during the construction of the final models. The eight strategies are defined in the table below in terms of their treatment of areas I, II and III, which were the areas significantly contaminated. It was agreed that all strategies should be advisory: i.e. no member of the public would be compelled to evacuate or whatever. The authorities would merely advise strongly that members of the public should comply with the suggested measures. It was also agreed that the costs of following the advice would have to be borne by the authorities. The terminology adopted was that 'evacuation' was a temporary measure (in this case for six months), during which time property would be kept secure for the population to return to at the end of the period. 'Relocation' was permanent: relocated households would leave their homes and communities for the foreseeable future and begin again elsewhere. Decontamination was interpreted as adopting procedures described by Brown, Heywood and Roed (1992) in their middle category.

The numbers of people affected by these strategies, the collective doses that would be averted, the maximum individual dose in the first month and the costs are given in Table 2 below. The costs were calculated using the figures given in Annex 3 and also those in Brown et al (1992). Note that it was assumed that decontamination of rural land costed the same as decontamination of urban land: 5 MSEK per km^2.

The decision model was built using the software package HIVIEW (Barclay, 1987). This package allows subjective scales of preference, such as those needed by the evaluation criteria social/political acceptability and psychological health effects, to be assessed and used easily. However, it does require that all scales increase in numerical value with preference: higher numbers always represent more preferred alternatives. Thus in the analyses that follow *higher* scores for costs, for instance, correspond to *cheaper* costs. Moreover, it is more convenient in using the package to normalise all scales to run between a minimum value of 0 and an maximum value of 100. The collective doses averted, the individual doses and the costs given above were transformed

[3] It should be emphasized that had the exercise been 'for real' many more strategies would have been considered. It is likely that in a real analysis the strategies would have been refined in each cycle of model building to capture the insights gained during that cycle. In the exercise it was decided to work with these rough strategies so that attention could be focused on other issues such as the evaluation criteria.

Strategy	No. Relocated	No. Evacuated	Collective dose averted (manSv)	Max. individual dose (mSv)	Cost (MSEK)
1	0	0	0	39	0
2	0	1805	213	23	917
3	0	2795	283	10	1812
4	0	6630	399	3	3562
5	1805	0	731	23	3015
6	1805	990	801	10	3909
7	1805	4825	917	3	5659
8	0	6630	290	3	597

Table 2: The numbers evacuated and relocated, the collective doses averted, the maximum individual doses and the costs of the strategies

linearly to 0-100 scales and their different 'relative lengths' taken account of in the weighting factors described below.

The scales for the other criteria were developed judgementally after much discussion and given the values below.

Psychological Health Effects:

Strategy	1	2	3	4	5	6	7	8
Score	20	60	80	100	0	20	30	50

Strategy 5 was given the lowest score because it relocated area I and thus probably causing considerable stress to the inhabitants there: yet, at the same time it did nothing for the inhabitants of areas II and III, leaving their stress from the concerns about contamination unaddressed. Strategy 4, on the other hand, treated all three areas sympathetically, offering the reassurance of decontamination policies without causing anyone the stress of permanent relocation. The other strategies were set into this scale using similar arguments. Strategy 1, which offered nothing to inhabitants of any area, was the subject of much debate. Its value of 20 was only adopted as a tentative first suggestion. However, since this strategy did not stand out in the final analysis as one the group were inclined to choose, there was no need to refine the value further.

Social/Political Acceptability:

Strategy	1	2	3	4	5	6	7	8
Score	0	100	100	100	60	60	60	30

Strategy 1 was felt to be the least acceptable to the public: the authorities could not be seen to be 'doing nothing'. Strategies 2, 3 and 4 were felt to be equally good in that the protective actions were clearly targeted and, if adopted, both appeared and would be the result of careful deliberation. Similarly, strategies 5, 6, and 7 were equally good although less so that 2, 3 and 4.

Flexibility:

Strategy	1	2	3	4	5	6	7	8
Score	0	70	85	100	0	15	30	100

Strategies 4 and 8 were felt to be equally the most flexible. They allowed some of the decisions concerning decontamination, if any, and return to the area to be left to the Spring: there was an opportunity to reconsider the decision then in the light of events. Strategies 1 and 5 were felt to be the least flexible in that they announced that no action was needed for areas II and III.

There was much discussion concerning the appropriate weights to use in the model. Initially, the weight of the radiation related health effects scale, i.e. the collective dose averted scale, was set to 100. The 'length' of this scale in manSv is 917. The cost scale has a length of 5659 MSEK. Since the recommended alpha value up to 600,000 SEK per manSv would be reasonable and since the model normalises the lengths of all scales to 100, this suggests a weight of $(5659/(917*0.6)) \approx 1000$ for the cost scale relative to the averted dose scale. The weights of the other scales were set judgementally. The maximum individual dose scale has a length of (39-3) mSv, i.e. 36 mSv. It was felt that this was three times as important as the maximum collective dose of 917 manSv which might be averted. Thus the weight of the individual dose scale was set at 300. Reducing the psychological effects from their worst level under strategy 5 to their best level under strategy 4 was considered equal in importance to averting a collective dose of 917 manSv, giving a weight to the psychological scale of 100. The social/political acceptability scale was similarly judged to have a weight of 100. In contrast, the difference in flexibility between the best and worst strategies on this the flexibility scale was judge to be only worth half the radiation related health effects scale and accordingly given a weight of 50. Thus the model analysed initially had the weights and scores given in Table 3.

		Strategy							
Criterion	Weight	1	2	3	4	5	6	7	8
Costs	1000	100	83	67	36	46	30	0	89
Radiation related health	100	0	23	30	43	79	87	100	31
Individual dose	300	0	44	80	100	44	80	100	100
Psychological	100	20	60	80	100	0	20	30	50
Social/political acceptability	100	0	100	100	100	60	60	60	30
Flexibility	50	0	70	85	100	0	15	30	100

Table 3: Weights and scores used in the initial analysis

4 Analysis of the Model

Multi-attribute value analysis begins by simply multiplying each score by the appropriate weight and aggregating to give an overall score for each strategy. A simple cost-benefit model comparing the costs of the strategies with the collective dose saved using an alpha value of 600,000 SEK is obtained by setting all weights to zero except for those on costs and radiation related health effects, which are left at 1000 and 100, respectively. Doing this gives a ranking of actions as given in Table 4. It can be seen that strategy 1, that of 'doing nothing' is just optimal. *Note:* The overall scores have been normalised so that a score of 100 on both cost and radiation related health scales would give an overall score or 100.

When all the weights are set to their values in Table 3, i.e. when all criteria are included in the analysis, the overall scores and ranking are as given in Table 5. It can be seen that introducing the other concerns modelled by the evaluation criteria swings the decision away from 'doing nothing' to strategy 8, which protects areas I, II and III by relocation or evacuation, but does not decontaminate any area. The optimality of this strategy arises because of the high cost of decontamination; 5 MSEK per km^2. Indeed, strategy 8 was introduced into the analysis to confirm this insight.

Strategy	1	2	3	4	5	6	7	8
Overall Score	90	78	64	37	49	36	9	84
Rank	1st	3rd	4th	6th	5th	7th	8th	2nd

Table 4: Overall scores for 'simple cost benefit' analysis.

Strategy	1	2	3	4	5	6	7	8
Overall Score	61	72	71	58	44	44	30	82
Rank	4th	2nd	3rd	5th	6th	6th	8th	1st

Table 5: Overall scores for the initial analysis based upon scores and weights in Table 3

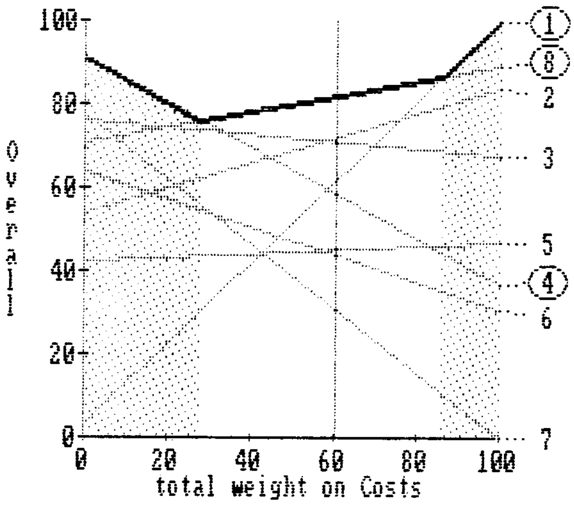

Figure 2: Sensitivity analysis on Costs.

The recommended 'alpha value' of 600,000 SEK was felt by many of the rather low or, equivalently, the weight on Costs was felt to be rather high. A sensitivity analysis on the weight on Costs is shown in Figure 2. Currently the weight on Costs is 1000 which is about 60% of the total weight in the model (1650). The vertical line marks this value. Corresponding to each strategy is a line which plots the overall score for a strategy against the percentage of total weight on Costs. The current optimality of strategy 8 is shown because its plot gives the highest intersection with the vertical line.

As the weight on Costs decreases from 60%, strategy 8 stays optimal until the weight is about 28% when strategy 4 becomes optimal. The change in optimal strategy is indicated by the shading in the sensitivity analysis diagram.

Further insights can be obtained by considering the plot shown in Figure 3. To interpret this figure, remember that increasing scores go with increasing preference. Thus lower costs have higher scores. The figure plots the overall score for all effects excluding cost against cost. Ideally one would like a strategy to be represented by a point in the upper right corner. It can be seen from this diagram that strategies 1, 8 and 4 lie on the upper right boundary (*efficient or Pareto*). Which is optimal depends on the weight put on Costs, which defines the trade-off between Costs and the other effects. Optimality moves from strategy 1 to strategy 8 and then to strategy 4 as the weight on Cost decreases from 100% to 0%: c.f. Figures 2 and 3. Strategies 5, 6 and 7 can clearly never be optimal without considerable changes in their of the scores and weights: strategies 1, 4 and 8 dominate them (i.e. offer a better choice). Strategies 2 and 3 are also dominated by strategies 1, 4 and 8; but far less clearly.

Values of 2 to 2.5 MSEK per manSv had been used on occasions in decisions within the nuclear industry. Obviously,in these decisions there had been other objectives than just monetary cost and dose reduction. It was argued that 'alpha values' are only 'ball park' figure. If 2.5 MSEK per manSv is used as the alpha value, the weight on the costs falls from 1000 to 240 and the overall scores and ranking becomes that given in Table 6.

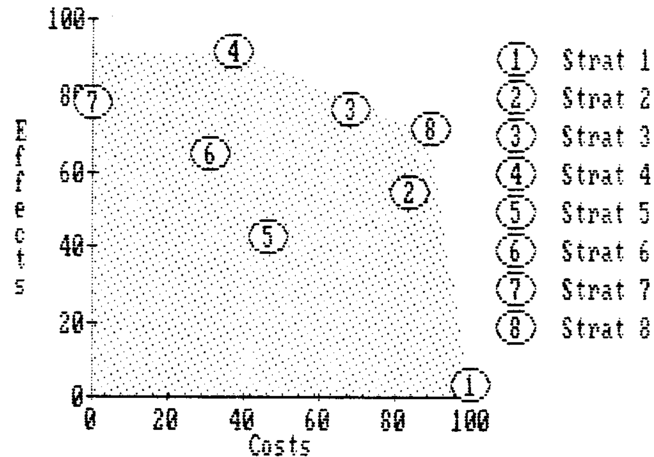

Figure 3: Plot of Effects against Costs.

Strategy	1	2	3	4	5	6	7	8
Overall Score	29	62	74	76	43	55	56	75
Rank	8th	4th	3rd	1st	7th	6th	5th	2nd

Table 6: Overall scores for the analysis when an alpha value of 2.5 MSEK per manSv is used.

Thus the analysis now points to strategy 4 being the best with strategy 8 a very close second. This corresponded closely to the general view of the participants. Indeed, many felt that in practice there would be little difference between the two strategies. Whichever was implemented, decisions concerning areas to be decontaminated and the methods to be employed would be deferred until the Spring. Strategies 4 and 8 simply provided best and worst case estimates of cost and collective dose saved for the course of action that the authorities would be likely to follow.

The above analysis developed over the two days as scores and weights were refined in the light of growing understanding of the issues. Many other sensitivity analyses were carried out, but none cast doubt on the general conclusions reached.

5 Conclusions from the Decision Conference

The decision for a majority of the participants was for a strategy somewhere between 4 and 8. Indeed, many participants felt that in practice there would be little difference between these strategies when implemented, since many subdecisions concerning decontamination and return from evacuation would be deferred until the Spring when more information would be available. Strategies 4 and 8 essentially give best and worse case costings on what would be done, along with upper and lower bounds on the dose averted.

It was also noted that in a conference focused on a real problem more strategies would have been considered. One member felt that evacuating and decontaminating areas I and II as well as selectively decontaminating area III would be a strategy which deserved serious consideration.

Strategy 1, the option of doing nothing, which would be the optimal course of action when averted collective dose and financial cost are the only attributes considered using the Nordic recommended 'alpha' value of 0.6 MSEK/manSv, was the least preferred alternative in the full analysis. It scored badly on every criteria except cost.

Many felt that it was important to retain flexibility in the strategy of protective actions, even if this increased the uncertainty for the population of Gotland which would not know exactly what would be done for several months. This emphasised even more the need for good communication and understandable presentations of the adopted strategy. It was also noted that flexibility would be needed in order to cope with the individual strategies adopted by people on Gotland, who might choose to not to follow the officially advised protective actions.

It was felt that the exercise had illustrated the problems inherent in radiation emergencies. However, a different situation with larger populations could have led to different results. None the less, the evaluation criteria, by and large, would have been appropriate to other situations, albeit with different emphases and weights. They would simply have led to a different choice of protective actions.

The exercise had been useful in that one needs to think about the issues before an accident happens.

All felt that more research and advice is needed on the psychological effects of such accidents and the effects of protective actions.

On the general matter of intervention levels, it was suggested that guidance should be flexible in order not to constrain the authorities into doing something which might not be appropriate to the particular circumstances of an accident. It needed to recognise, for instance, that one can evacuate small numbers of people but not large cities.

6 Reflections on Decision Conferencing

Decision conferencing is a technique – process might be a better word – which seeks to support to a group facing a complex strategic problem. At a decision conference, the group are aided in their discussions by a **facilitator** and, usually, an **analyst,** who attend to the process and decision modelling, leaving the group free to concentrate on the content of their problem. Neither the facilitator nor the analyst are expert in the decision problem facing the decision makers. They assist the conference by keeping the discussion focused on the problem in hand, and ensuring that all present both contribute their views and fully understand the points made by the other decision makers, helping create a shared understanding of both the problem and the way forward.

The facilitator and analyst build decision models of the choice facing the group, projecting the results on a large screen for all the group to see. Typically a sequence of models is built, each a revision or development of the previous, to pace with the group's evolving view of the problem. The modelling invariably leads to much discussion within the group. During the sensitivity analysis phase the results of the model are examined using a wide range of numerical values for the judgements upon which the group cannot agree. Often the final ranking of alternative strategies is unchanged or insignificantly affected by variations across the whole range of numerical values proposed by members. In some cases, of course, significant changes in the ranking do occur and the group must discuss the values further.

French (1992) argues:

»The choice of intervention levels and other countermeasures following a nuclear accident is not simply a technical problem. Political, social, economic and other non-tangible issues are inevitably involved. Decision conferencing is a technique which gathers together all important parties to the decision making for a two day meeting at which all relevant concerns can be discussed and possible protection strategies evaluated. The process is supported by the use of interactive software through which multi-attribute and other decision models may be built to help the decision makers explore the issues. Typically, decision conferences are creative events, constructing strategies as well as evaluating them.«

The meeting reported here is clearly a test of that claim: and, indeed, the third objective of the meeting was to explore the potential of decision conferencing in such circumstances.

During the concluding discussion several points were made which are relevant to this issue.

- All had felt that having many varied perspectives present in the meeting have been useful. It had contributed to a fuller and shared understanding of the problems likely to be faced in the event of a major nuclear accident.
- Most felt that the software had been useful. Its graphical, visual display of sensitivity analyses had helped focus discussion. Some commented that they already use projected computer output in their meetings and the extensive use of such during a decision conference was a natural progression from this.
- There was a suggestion that the meeting would have progressed faster if the evaluation criteria had been defined more fully earlier. However, that may be a comment made with hindsight. It is commonly found in decision conferences that one repeatedly revisits the definition of the criteria during the two days as understanding of the issues evolves. Such an iterative, evolutionary process seems almost inevitable. Ab initio definition of criteria is very difficult.
- Because of the nature of the exercise, the set of strategies was kept more or less fixed during the conference. If the conference had been for real, the set of strategies would undoubtedly have evolved as understanding of the issues, cost and effects grew. It is worth noting here that the introduction of strategy 8 occurred because the relative expense of decontamination became apparent during the analysis of a preliminary model.
- Much more technical support would have been available in a real conference. For instance, when a new strategy was suggested, there would have been manpower available to cost it and to predict its effect in terms of averted dose and maximum individual dose. This would have meant that discussion might have developed faster and in a more focused manner than it did at the meeting.
- There was a feeling that the meeting was too large at nearly thirty participants. Much of the reason for its size was to ensure adequate

representation of the five Nordic countries. Certainly in real circumstances, a decision conference would be smaller, and the grouping more tightly focused on the issues deriving from real circumstances. So perhaps this would not have been a problem in a real conference.

- One participant suggested that whether or not decision conferencing would be a useful tool in the event of a real emergency, it was clearly a useful tool in stimulating discussion in planning and emergency preparedness, as it had been at this conference.

7 Acknowledgements

The BER-3 group are grateful to the participants for taking part in the event fully and giving their advice and judgements freely. They are grateful for permission to report discussion and conclusions from the conference.

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Annex 1: Participants

The following participated at the decision conference:

DK	Knud Bork Kristoffersen, Civilforsvarsstyrelsen, H. P. Ryder, Civilforsvarsstyrelsen, Kåre Ulbak, Statens Institut for Strålehygiejne, Kasper Vilstrup, Vilstrup Research, BER-3, Ole Walmod-Larsen, Risø, BER-3, Henny Frederiksen, BER-3 (secretary),	SF	Antti Vuorinen, STUK, Tapio Rytömaa, STUK, Kari Sinkko, STUK, BER-3 (analyst), Hannele Aaltonen, STUK, Anneli Salo, BER-3, Janne Koivukoski, Inrikesmin., Markku Haranne, Nylands len, Liisa Eränen, Univ. of Helsinki, BER-3,
S	Gunnar Bengtsson, Statens Strålskyddsinstitutt, Jack Valentin, Statens Strålskyddsinstitutt, Carolina Dickson, Enhet 6, Dept. f. miljö och nat.res., Carl Axel Hermansson, Försvarsdept., Erik Österberg, länsstyr.i Hallands län, Lars Johan Svensson, länsstyr.i Hall.län, Ola Fischer, länsstyrelsen, Malmöhus län, Claes Jöran Dahlqvist, länsstyrelsen, Kalmar län, Monica Gustafsson, Vattenfall, BER-3,	N	Steinar Backe, SSV, Erik Anders Westerlund, SSV, Svein Uhnger, Fylkesmannen i Finmark, Arne W. Karlsen, Fylkesmannen i Buskerud,
		IS	Sigurður Magnusson, SIS, Reykjavik,
		GB	Simon French, Leeds University (facilitator).

Annex 2: Summary of Scenario

Several days before the conference, all participants were sent the following scenario, which had been developed for the purpose by Kari Sinkko and Ole Walmod-Larsen assisted by Anneli Salo, all of the BER-3 Project. Plume dispersion and dose predictions were calculated by Jukka Rossi, Technical Research Centre of Finland using the software package ARANO.

Scenario for the Nordic Seminar Decision Conference Dec. 8-9th 1992, DK

It is a difficult task to make a scenario relevant to all participants coming from almost all corners of Scandinavia. We suggest however the following:

A serious reactor accident has happened in Lithuania at a site around five hundred kilometres east of the island of GOTLAND.

It could have been: KIRKENES or ÅLAND or HEYMAY or BORNHOLM or LÆSØ or ...

– Anyhow it is within YOUR area of responsibility!!

In the morning on Tuesday Dec. 1st. information was received from Lithuania, at the contact point pursuant to the convention on early notification, that a serious accident had happened at 2 o'clock in the morning at the RBMK REACTOR STATION, unit 1. As a consequence of the accident a large release of radioactivity had taken place.

In the following days contact points received an increasing flow of details about the accident from Lithuania. A still unknown amount of fuel in the unit 1 reactor had been overheated resulting in **a sudden, large release of fresh fission products to the atmosphere.**

Of still unknown reasons, several fuel channels had probably ruptured simultaneously and the massive concrete slab above the reactor had lifted. As all the fuel channels are fitted to this slab it can be expected that most of them have been damaged. For the same reason, the majority of the control rods failed to function. Due to the fact that the slab went back into its position, the release was however limited and it was further possible to supply some cooling and to limit and later extinguish a graphite fire.

The weather in the area from Lithuania to Gotland Tuesday night and Wednesday morning was stable with steady winds from the east.

In the Gotland area at noon time Wednesday a **front passage from the west made the weather unstable with showers of rain and later heavy showers of wet snow.** Thursday and Friday falling temperatures and decreasing winds from the west were prevailing in the Gotland area. The mainland had - and still has - stable conditions with clear sky and weak winds from the west.

Based on the weather forecast the flight monitoring team was sent east and southeast of Gotland over the Baltic sea on Wednesday morning.

The preliminary dose predictions and the observation of the plume by the flight monitoring team on SE of Gotland made it clear that the inhabitants of the island had to be warned and iodine tablets distributed. People were also advised to listen to the radio and follow the orders to be given by the authorities.

No deterministic effects were predicted.

A few hours later the monitoring team on the east coast reported a rise in the outdoor dose rate from the ca. 80 nSv/h background to 50 μSv/h.

This confirmed for the experts that **a plume had arrived** and, as they were aware of the possibility of high inhalation doses, they gave advice of sheltering the population of the entire Gotland.

Immediately, at 1430 Wednesday, the Gotland authority decided upon

Sheltering and Intake of Iodine Tablets

for the whole population of Gotland.

Gotland's total number of inhabitants is 56 000. Approx. 21 000 are living in Visby and the number of pregnant women is estimated at 550.

Further monitoring teams and a high ranking expert were dispatched to the island by helicopters to advise the local authorities, take on-the-spot measurements and collect samples for analysis.

Monitoring teams were also put on guard along the mainland coastline towards Gotland. All on-line monitoring stations in the region report normal conditions.

Wednesday at 1800 a meteorological station on the North end of Gotland reported a layer of 3 cm ice covered by 10 - 20 cm of snow, clear sky, decreasing wind towards E and temperatures falling below -10°C.

Thursday morning the experts described the situation as follows: The heavy rain/snow over the upper part of Gotland had caused a substantial wet deposition of fresh fission products during a plume passage in the afternoon hours of Wednesday.

The plume had obviously passed the island from SE, then turned north meeting the showers over the northern end and then returned towards the east, leaving a deposition of radioactivity north of a line ca. 10 km North of Visby city going towards SE.

North of this line the outdoor dose rate levels at 1 m above ground were around 60-70 μSv/h increasing to 400 μSv/h 30 km NE of Visby and further to 2 - 3 mSv/h at the northern end of Gotland.

40 μSv/h was reported from the airport a few km north of Visby.

Towards the south from Visby levels rapidly decreased. 50 km south of Visby was measured 3 times background.

The preliminary sample analyses pointed at a similar pattern in the Cs-137 levels of deposition.

In the southern part levels of few kBq/m^2 were seen. North of Visby was found 50 kBq/m^2. Towards NE these levels grew: 30 km NE of Visby: 0.3 MBq/m^2. Towards Fårö Sound was found several MBq/m^2, and a maximum was measured in a sample from the centre of Fårö island.

Thursday afternoon the telecommunication system of Gotland became overloaded. This lasted till Friday morning. In this period the on-line monitoring station in Visby did not report. Back on-line it showed 30 μSv/h.

After the situation briefing Thursday morning the experts came to the conclusion that **the plume had left Gotland Wednesday night. Therefore the sheltering action should be relieved immediately for the whole island.**

It was judged however - although the information available was incomplete - that the doses to be received by the inhabitants of the Fårö island and by the inhabitants living on the main island at the area from Fårö Sound to 5 - 8 km SW of Fårö Sound would become so high that they would have to be evacuated as soon as possible.

At 10 o'clock on Thursday morning the Gotland authority decided to

Relieve the Sheltering for Gotland and Evacuate the Inhabitants in the Above Described Area.

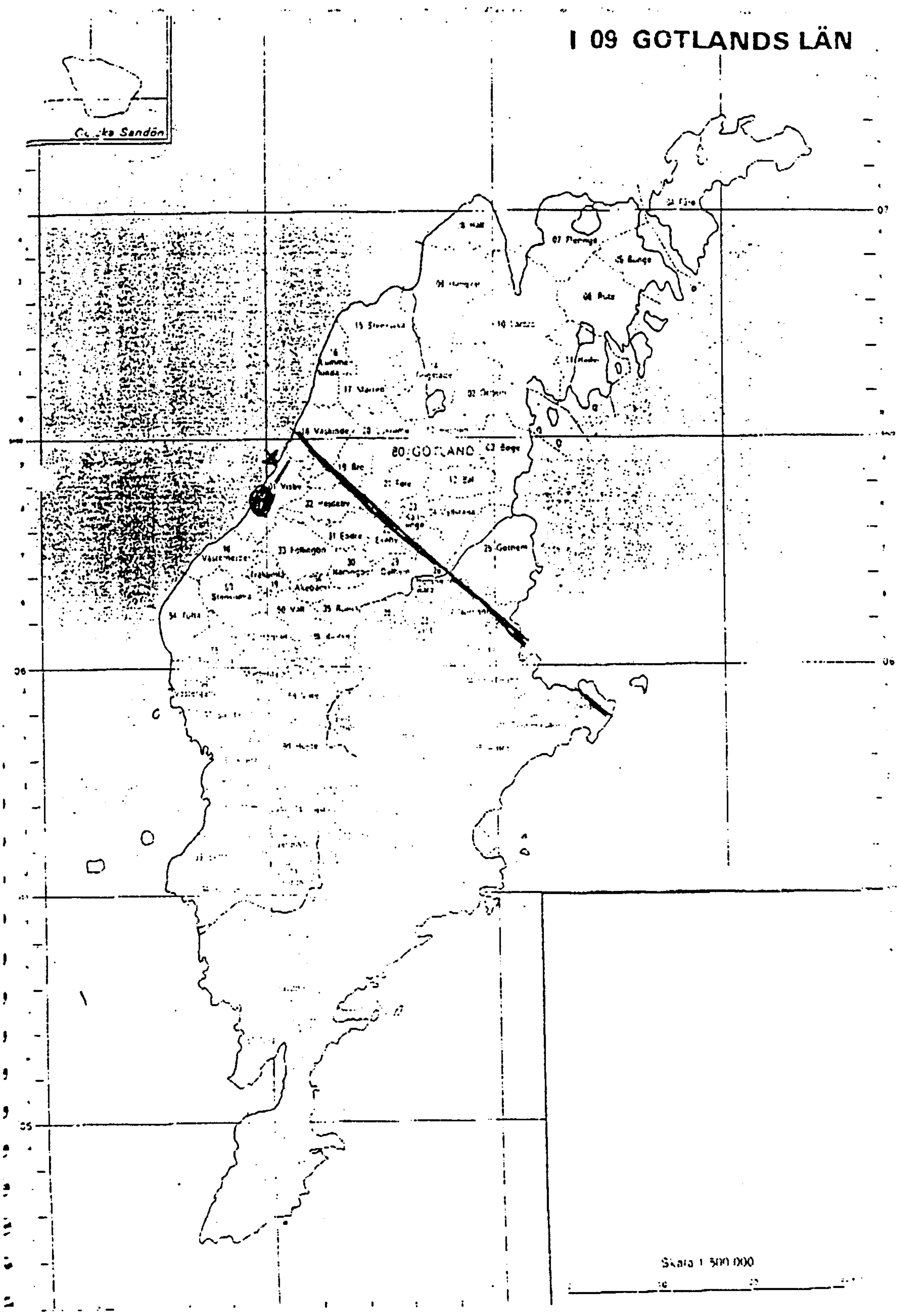

Figure A2.1: Map of Gotland.

Annex 3: Detailed Scenario

The following detailed scenario giving technical data was sent roughly two days before the conference to those participants who would have had such information (albeit in rather larger quantities) in the event of a real accident. These details were available to all participants at the conference.

The Nordic Seminar
Decision Conference Dec. 8 - 9th 1992, CFH, DK

With reference to the letter dated November 27th 1992 hereby further information is given supplement to the scenario described. In the tables below we have gathered all the data which have been measured or predicted and which is assumed to be available at this point of time. The information shown refer to six different fallout areas of Gotland. Their positions can be seen at the attached map.

Radiation Situation

Based upon information received from Lithuania at the contact point, the following fractions of the total core inventory are assumed to have been released to the atmosphere over a period of 12 hours:

Noble gases	all
Iodines	few ten's of percent
Tellurium	few percent
Cesium	few percent
Ba, La, Sr, Ru, etc.	few tenths of percent

The following shielding factors have been assumed to be relevant for Gotland and have been used in the calculations:

	Cloud	Deposition	Inhalation
Wooden houses	0.9	0.3	0.3
Block houses	0.3	0.03	0.3

Table I. Measured average individual doses during the first day (mSv), dose rates on thursday morning (mSv/h), and ^{137}Cs-fallout (MBq/m²) in various areas of Gotland, see the attached map.

Area	I	II	III	IV	V	VI
Dose for normal conditions (mSv)*	33	20	8.6	2.6	0.86	0.04
Dose when sheltered (mSv)	16	10	4.3	1.3	0.43	0.02
Outdoor dose (mSv)	84	50	22	6.7	2.2	0.1
Dose rate (mSv/h)**	2.5	1.5	0.6	0.2	0.06	0.003
^{137}Cs-fallout (MBq/m²)	5.0	3.0	1.3	0.4	0.13	0.006

* Normal living conditions, i.e. 10% outdoors and 90% indoors
** Outdoor, Thursday morning

Table II. Predicted average individual and collective doses in the subsequent six days in various areas of Gotland.

Area	I	II	III	IV	V	VI
Dose(mSv)*	47	28	12	3.8	1.2	0.06
Collective* dose(manSv)	85	28	47	8.9	8.6	2.4

* Normal living conditions

Table III. Predicted individual doses (individual effective dose; mSv) for normal living conditions in the six fallout areas considered for various time scales. The dose accumulated during the first week is subtracted.

Area	I	II	III	IV	V	VI
1 Month	39	23	10	3.1	1.0	0.05
6 Months	86	52	22	6.9	2.2	0.10
1 Year	109	65	28	8.7	2.8	0.13
3 Years	151	91	39	12.0	3.9	0.18
10 Years	218	131	57	17.4	5.7	0.26
30 Years	317	190	82	25	8.2	0.38
70 Years	405	243	105	32	10.5	0.49

Table IV. Predicted collective doses (manSv) for normal living conditions in the six fallout areas considered for various time scales. The dose accumulated during the first week is subtracted.

Area	I	II	III	IV	V	VI
1 Month	70	23	38	7.3	7.0	2.0
6 Months	155	51	84	16	15	4.0
1 Year	197	64	107	20	20	5.2
3 Years	273	90	150	28	27	7.2
10 Years	393	130	219	41	40	10
30 Years	572	188	314	59	58	15
70 Years	731	241	403	75	74	20

Table V. Predicted individual ingestion doses (committed effective dose; mSv) to people for different time scales in the six fallout areas considered.

Area	I	II	III	IV	V	VI
1 Year	63	38	16	5.0	1.6	0.08
3 Years	126	76	33	10	3.3	0.15
30 Years	181	108	47	14	4.7	0.22

Milk 300 kg, meat 35 kg, grain 70 kg, green vegetables 40 kg, root vegetables 30 kg per capita is assumed to be consumed in a year. Foodstuffs are assumed to be produced and consumed in the same area.

Taking into account that the fallout area is relatively small we assume that it is feasible to supply uncontaminated food to the entire Gotland.

Monetary Costs of Relocation

Table VI. Assessed monetary costs of relocation (MSEK) in the three fallout areas considered for various time scales.

Area	I	II	III
3 Years	3 800	500	1,700
10 Years	1,300	800	2,600
30 Years	2,100	1,400	4,200
70 Years	3,000	2,200	5,600

Demographic Data

Table VII. The number of inhabitants in various areas considered and the area of the land (km²).

Area	I	II	III	IV	V	VI
Number of inhabitants	1805	990	3835	2350	7020	40,203
Area	150	160	280	300	580	1,300

Assessment the Monetary Costs of Relocation

Calculation of the monetary costs arising from relocation is largely based on methods presented in the COCO-1 report. The costs of no-action is assumed to be negligible.

Transport Costs:

The transport costs by road for both organised transport using buses and private cars and assuming that the average distance moved is 100 km, is estimated to be 60 SEK/person (running costs of a car per km is 2.5 SEK). The transport costs by boat (ferry) per person is 100 SEK.

Transport costs per journey per person is 160 SEK.

Loss of Income:

It is assumed that if people are relocated, then they will also be unable to reach their workplace and that the contribution they would have made to the economy will be lost. This loss can be assessed from GDP per capita (GDP in Sweden is 160,000 SEK). Note, the loss of income of farmers is included. A mean recovery time of economy around two years is thought to be appropriate as default value.

The loss of income for all relocation strategies per person is 320,000 SEK.

Food and Accommodation Costs:

To avoid double counting the simple approach adopted here is to estimate only the cost of lost accommodation. In choosing the time at which the costing should be stopped to be the same time as the cutoff time for loss of income, two years, and if the GDP used includes the housing component, then accommodation and also food costs are included in costs of lost income.

Costs of Lost Capital Services:

The cost of lost capital services is caused by the acceleration of depreciation due to lack of maintenance and by loss of interest on the original investment. These costs caused by the loss of non-residental capital stock, housing and land are taken into account after the cutoff time, two years, because GDP includes the interest on capital value. Note, the loss of income is calculated for the two first years using the GDP. The GDP does not include consumer durables and therefore the these costs begins at the time of the accident. The rebuilding of industry, public buildings, homes etc is not included as costs, as these costs may be regarded as being equivalent to the costs of the lost capital value of the lost area.

It is assumed that the resettlement process takes one year and that the costs therefore continue for an extra year.

The value of land and its assets for various categories are as follows:

- non-residential capital stock; 150,000 SEK/person,
- housing; 150,000 SEK/person,
- consumer durables; 110,000 SEK/person,
- land:
  - urban areas; 150 MSEK/km^2
  - rural areas; 1.3 MSEK/km^2.

Rates of interest and depreciation:

- interest rate, 5%,
- depreciation rate:
  - stock and dwellings; 5%
  - consumer durables; 10%.

Costs of Lost Capital Services for Various Relocation Strategies (without discounting).

	Capital (MSEK/person)	Urban Land (MSEK/km^2)	Rural Land
3 year	0.11	15	0.13
10 years	0.30	67	0.58
30 years	0.59	217	1.88
70 years	0.69	517	4.50

»Normal« frequences of cancers in Finland in a year

Leukaemia:	Adults:	5-7/100,000
	Children:	5/100,000
	Mortality:	50%
Thyroid:	Adults:	1-2/100,000
	Children:	0.1/100,000
	Mortality:	10%
All others:	Adults:	200/100,000
	Children:	100/100,000
	Mortality:	50%

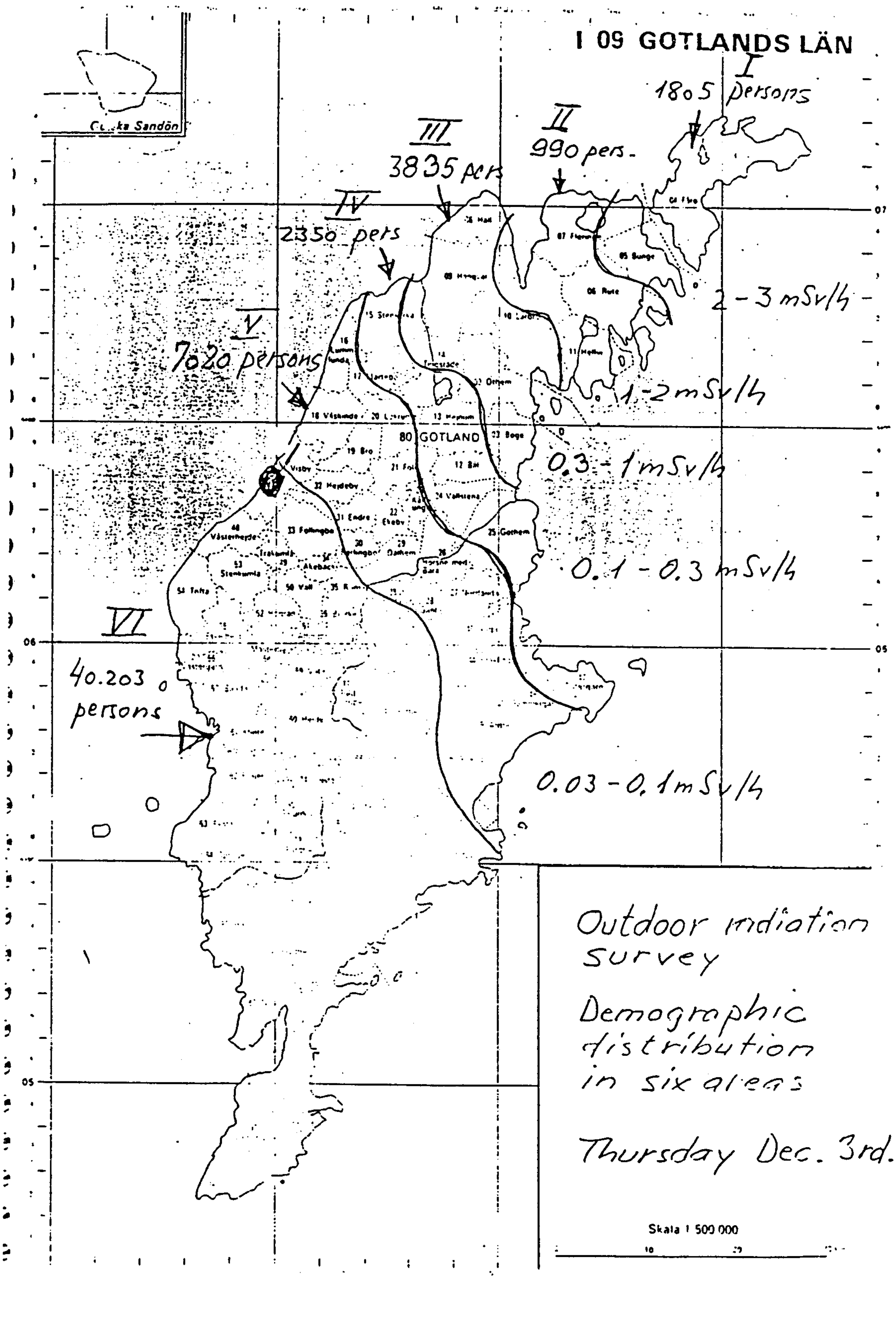

Figure A3.1: Map of Gotland showing distribution of contamination.

Bibliographic Data Sheet Risø-R-676(EN)

Title and author(s)

Decision Conferencing on Countermeasures after a Large Nuclear Accident
Report of an Exercise by the BER-3 of the NKS BER Programme

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ISBN	ISSN
87-550-1887-4	0106-2840

Dept. or group	Date
Nuclear Safety	January 1993

Groups own reg. number(s)	Project/contract no(s)

Pages	Tables	Illustrations	References
24	12	5	8

Abstract (Max. 2000 characters)

The BER-3 Project of the emergency preparedness programme (BER) of the Nordic Co-operation Organisation (NKS) organised a decision conference to address the following objectives.

1. To achieve a common understanding between decision makers and local government officials on the one hand and the radiation protection community on the other of the issues that arise in decisions in the aftermath of a major nuclear accident.
2. To identify issues which need to be considered in preparing guidance on intervention levels.
3. To explore the use of decision conferencing as a format for major decision making.

To achieve these objectives the participants were invited to consider a scenario of a hypothetical radiation accident. The scenario assumed that appropriate early protective actions (sheltering, issuing of iodine tablets, etc.) had been taken and that the conference was meeting some eight days into the accident to consider medium and longer term protective actions, particularly the need for relocation of certain areas. By the end of the conference, considerable consensus on the general form of the strategy had emerged. Moreover, there was a better understanding of the evaluation criteria against which such a strategy needed to be developed.

Many felt that it was important to retain flexibility in the strategy of protective actions, even if this increased the uncertainty for the affected population, who would not know exactly what would be done for several months. This emphasised even more the need for good communication and understandable presentations of the adopted strategy. All felt that more research and advice is needed on the psychological effects of such accidents and the effects of protective actions. It was felt that the exercise had illustrated the problems inherent in radiation emergencies. However, a different situation with larger populations could have led to different results.

It was agreed that the exercise had been useful in meeting the need to think about the issues before an accident happens. On the general matter of intervention levels, it was suggested that guidance should not constrain the authorities into doing something which might not be appropriate to the particular circumstances of an accident. It needed to recognise, for instance, that one can evacuate small numbers of people but not large cities.

Descriptors INIS/EDB

DECISION MAKING; EMERGENCY PLANS; PLANNING; POPULATION RELOCATION; REACTOR ACCIDENTS; REMEDIAL ACTION

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8. DECISION ANALYSIS OF PROTECTIVE ACTIONS IN FOREST AREAS

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A nuclear accident itself and the introduction of protective action entail risks to the people affected, monetary costs and social disruption. As far as the society is concerned the values which enter decisions on protective actions are multidimensional. People have strong feelings and beliefs about these values, some of which are not numerically quantifiable and do not exist in monetary form. These problems, often including mutually conflicting objectives and uncertainties and are difficult to control simultaneously, cannot be undertaken without careful consideration of the essential consequences of decisions. Decision analysis can be applied in planning intervention, this helps in rendering explicit and apparent all the factors involved and evaluating their relative importance. In this study recovery operations to clean up a forest environment in the event of a hypothetical radiation accident in a nuclear power plant were analyzed and discussed to determine what would be appropriate intervention levels in protecting the public, workers and the environment. The values considered essential in the decision were included in the analysis and their importance on decision making process is discussed.

8.1. INTRODUCTION

Situations in which the radiation sources, the pathways and the exposed individuals are already in place when decisions on remedial actions are considered, are called *intervention* situations. In these situations the doses which are received or are likely to be received can only be reduced by remedial actions. The basic principle when implementing of protective actions is that intervention should be *justified* and *optimized*, i.e., the introduction of a protective measure should achieve more good than harm and the net benefit should be maximized (IAEA91, ICRP91). Decision analysis is a suitable method for helping to solve societal problems of this type.

Research over the past 30 years has transformed the abstract mathematical discipline of decision theory to a potentially useful technology known as *decision analysis*, which can assist decision makers to handle large and complex problems together with their attendant flow of information. Decision analysis is not intended to solve problems directly. It's purpose is to produce insight and understanding. In the light of that understanding the decision maker can make better decisions. Those interested in the theory of decision analysis may consult the literature (Fr88, Go92, Ke76, Wi86). This report provides an application how decision analysis can be used when planning protective actions.

As initially presented the background information is generally limited or incomplete in decision making. A careful analysis of the problem indicates what further information is needed to find the best course of action. Thus the aim of this study was not only to find the best protective actions, but also to indicate the information that should be catered for or revised. If in the light of revised information or gained insight new, feasible actions are identified, the analysis should be revised.

The following analysis deals with protective actions for contaminated forest areas. The actions which most probably have to be taken on cultivated or natural foodstuffs, were excluded, although they might have had an effect on the analysis. Because of the high contamination levels considered in this study there would certainly be restrictions on the use of natural foodstuffs.

8.2. ACCIDENT SCENARIO

For the purpose of the analysis it was assumed that a hypothetical accident had happened at a nuclear power plant in Finland leading to a core melt and to a very severe - presumably worst possible - contamination of the environment (cf. chapter 3). 10% of fission products and 1% the transuranics were assumed to have released from a 700 MW BWR reactor. It was further assumed that the accident had happened in summer time and there had been only dry deposition. As a consequence of the accident the forest areas given in Table I were contaminated.

Table I. Fallout area in forest land and the contamination levels after a hypothetical reactor accident.

Nuclide	Area I 1.5 km^2	Area II 22 km^2	Area III 1660 km^2
^{137}Cs mean	> 100 MBq/m^2	10-100 MBq/m^2 20 MBq/m^2	1-10 MBq/m^2 2 MBq/m^2
^{90}Sr mean	> 77 MBq/m^2	7.7-77 MBq/m^2 15 MBq/m^2	0.8-7.7 MBq/m^2 1.5 MBq/m^2
^{239}Pu mean	> 22 kBq/m^2	2.2-22 kBq/m^2 5 kBq/m^2	0.2-2.2 kBq/m^2 0.5 kBq/m^2

8.3. CONCERNS AND ISSUES

From the radiation protection point of view the aim of protective actions is to reduce the individual as well as the collective doses to the public and workers, and also to reduce radiological impacts on the environment. Concerning the forest, the aim is also to keep the area in, or bring it back into production by feasible decontamination.

Intervention will affect the exposure pathways, and it should be carefully considered, that the total detriment of the population is reduced and, e.g., the dose is not reduced in one group by increasing it in another group. For example, the decontamination and the reduction of exposure to the population can be achieved only by increasing the doses to workers, who are carrying out the intervention measures.

The use of dose limits as the basis for the deciding on intervention might involve actions that would be out of all proportion to the benefit obtained and would thus conflict with the principles of justification and optimization. ICRP therefore recommends against the application of dose limits or any predetermined limits for deciding on the need for intervention. However, the position of workers carrying out recovery operations is different. These actions, non the less even they are in response to an accident, can be planned and optimized in advance and therefore it is recommended that workers undertaking recovery operations should be subject to the normal system of radiological protection and dose limits should be applied.

The intervention measures entail also non-radiological risks to the population and the workers caused by various kind of accidents. The risks which are directly associated with remedial actions should be taken into account when making decisions on intervention. In addition, there might be radiological risks caused, for example, by forest fires. Fires would result in the resuspension of radionuclides and an increasing number of individuals will be subject to radiation.

Psychological stress could lead to health effects of a comparable nature to those arising from the contamination and at the same time reduces the quality of life significantly. A majority of the population in a contaminated area may show varying degrees of stress reactions, but stress could also be a consequence of a protective action. Stress can be reduced by taking appropriate actions, such as actions which decrease the dose of population, but at the same time this would lead to an increase in exposure among the intervening workers.

Perceived risk, in addition of health effects, can have serious economical and social consequences, e.g., to the forest economy and industry. The public opinion and the perception of risk could result in consequences which reduce the benefit of actions or make their implementation impossible. For example, in a limited accident the population (and the forest industry) might not accept products made from wood grown in the contaminated area although, e.g., only bark and branches of the trees were contaminated and the contamination could be removed very efficiently. The industry might think that the risk of being discredited by using contaminated materials is too great, and thus refuse to use even slightly contaminated raw materials.

Individual people and families own 75% of forests in Finland and the average area of a forest estate is 0.35 km^2. Thus, there would be nearly 5000 private forest estates in the contaminated area considered in this study. Land owners would be worried about their property and incomes, and so there would be considerable stress within this group of people.

The fallout would reduce the value of contaminated land for decades, but it would also reduce the value and the quality of the surrounding areas. The reduction in quality of the environment would take place also in the vicinity of disposal sites and around power stations burning radioactive wood.

Remedial actions would cause monetary costs to the individual land owners, industry and the society. The costs would include transportation costs, loss of income, costs of the control of the area and costs of lost capital services. Also the question of reimbursing land owners for any remedial actions would arise. If any compensation is paid, either in full or in part, it means that the costs to individuals would now be costs to society. None the less, would the cost of action be a limiting factor? The economic impact of an accident may not be entirely negative. The activities may have positive effect on the economy, such as generation of employment or production of energy by burning wood produced in the contaminated area.

8.4. DECISION MODEL

8.4.1. Action alternatives

The essence of decision analysis is to break down complicated decisions into small components that can be dealt with individually and then recombined logically. The process of breaking something down into its constituent parts refers to the process of developing an overall analytic structure. The formulation of the problem is *to identify what can be done and what might happen as a consequence*. In this process construction of a *decision table* or a *decision tree* is a very helpful method. Figure 1 shows a decision tree used to analyze the remediation strategies of contaminated forests. Decision tree compactly represents a set of scenarios. Any path from left to right through the tree constitutes a scenario. We will discuss in more detail these scenarios when discussing the strategies which can considered for cleaning up the contaminated forest.

One main stage in the decision analysis is to identify the alternative courses of action. In considering an intervention, all feasible actions should be defined - including no action. When defining an action, its feasibility should also be considered; could it be implemented in practice as it has been planned? For instance, it should be taken into account that society is not neutral to the choice of action. The remedial actions which were considered in this study are no action, control of wood material, control of access and removal of various parts of vegetation, i.e., trees, stumps, udervegetation and/or soil.

If in any of the defined areas (I, II or III in this analysis) no recovery operation, control of wood material or control of access is taken, the contamination is left in full in the forest. The amounts of radioactive materials will decrease with time through radioactive decay and by resuspension, which will cause transfer of radionuclides also to habilitated areas exposing unidentified people (projected release scenarios). The resuspension over 70 years is estimated to be 15%. Also, if the use of contaminated wood material is not restricted, its use will cause transfer of radionuclides to living environment. It is estimated, that the total amount of transfer in this pathway will be 30% over 70 years.

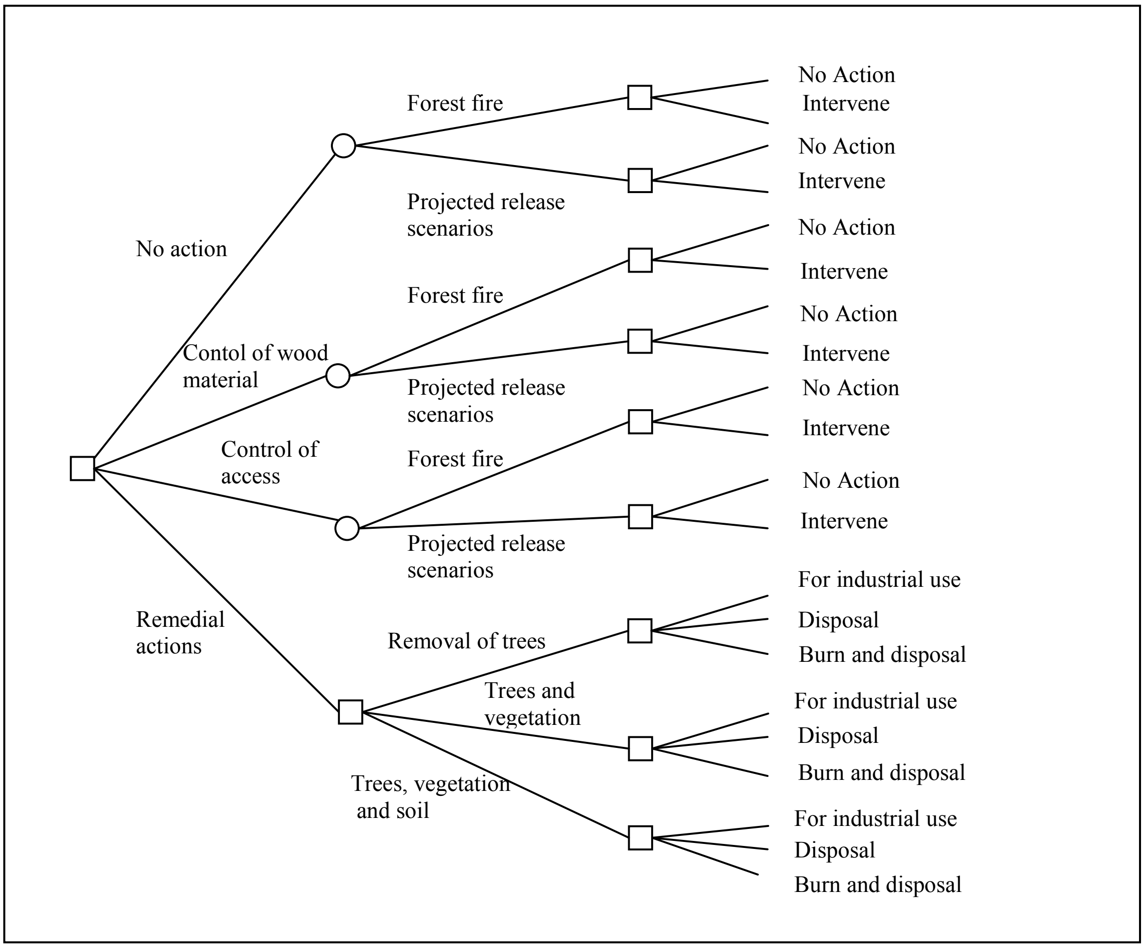


Figure 1. Decision tree to analyze the cleanup strategies of contaminated forest.

A forest fire will cause a spread of radionuclides. According to the statistics there are a few hundred forest fires in Finland every year in which 0.05 km^2 of forest is burnt on average. The probability, that a forest fire would occur in the contaminated area is less than 0.01 in a year. By assuming that 50% of radionuclides being in forest will be released in a fire, gives the result that the expected collective dose to the public would be very low (few ten's of mmanSv) as compared to the other pathways. Thus a forest fire is not an important scenario when considering the actions to be taken.

Decontamination of forest could be done by removing trees, stumps, undervegetation and/or soil. If all these are removed after two years it is estimated that 20% of radionuclides will remain in the contaminated area. When only trees and undervegetation are removed after two years the cleanup efficiency is estimated to be 60% in practice. During the first season the radionuclides are mostly in canopies, and by removing the trees the practical efficiency of decontamination is estimated to be 50%.

Based on the information mentioned above six strategies as defined in Table II were considered.

Table II. Strategies for recovery operations in forest areas defined in terms of their effects on the areas I, II and III.

Strategy	Removal of trees [a]	Removal of trees and underveg etation [b]	Removal of trees, underveg etation and soil [b]	Control of access [c]	Control of wood material	No action
1	II		I	I, II		III
2	II	I		I, II		III
3		I, II		I, II		III
4				I, II		III
5				I, II, III		
6			I	I, II	III	

a) Action is taken during the same season.
b) Action is taken two years after the fallout.
c) Projected period for control of access is 70 years.

Actually many more strategies could be considered by combining the areas and possible decontamination strategies. The limiting the analysis to those above would, however, not reduce the possibilities for evaluating the best course of action. Some strategies are not even feasible, e.g., it is not possible to remove the trees in area I during the same season, because the individual doses would be unacceptable high; the dose rate would be one mSv/h. Furthermore, as is indicated in the decision tree, there are three different methods to treat contaminated and removed trees:

1. Industrial use of trunks in sawmills or in pulp industry. Disposal of branches and barks as such or as ash after burning as fuel.
2. Chipping the trees, branches and stumps and burning the chip in power stations. Disposal of the remaining ash.
3. Disposal of trees as they are or in the chipped form.

These optional methods will be discussed below in more detail.

1. Industrial use. The method can not be easily applied. In principle, if trees are barked in the same or in the following season, the wood itself will be clean and the activity will be mostly still in the bark and in the branches. However, only big trees are barked in sawmills nowadays. There is a lack of machines suitable for this action to be done in the forest. Also, the distribution of contamination during the barking process would be unacceptable high.

If the trees are used in the chemical pulp industry, the pulp will be clean because during the process the radionuclides will be removed and they remain in the waste sludge. The contamination of machines would be a problem.

The most serious problem is the public opinion. Although it could be shown that the products made of contaminated material would be free from radioactivity, the industry and the population would in all probability not accept them. Public can be very suspicious about this kind of products as was demonstrated after the Chernobyl accident. Also, clean wood material would be available. Thus, the industrial use of contaminated trunks have to be rejected as a strategy.

2. Burning of wood before disposal. There are small (5 MW) and large (20 - 200 MW) power stations in every Nordic country, which are suitable for burning chipped wood material. If proper electrostatic precipitators are used, 95-99% of radionuclides will remain in the ash. The amount of waste ash to be disposed would be small. An ash contents of 5% have been used in the calculation. However, there will be some suspicion of burning radioactive material, especially among the population in the vicinity of the power stations.

3. Disposal of all material as such. Undervegetation, litter, humus and soil have to be disposed as such. Wood material can also be disposed as it is, but chipping the trees, branches and stumps, however, will help in the disposal and rotting of material. In all cases, final disposal cannot be undertaken before the organic material is rotten.

Burning of wood before disposal and disposal of all material as such are the two optional methods considered in the analysis.

8.4.2. Objectives and attributes

Having found the courses of action, the next main step is to identify all attributes (measures in figure 2) relevant to the decision. One technique to identify an operational set of attributes, is to start by listing all important objectives (goals in figure 2), such as minimizing health detriment, monetary cost and social disruption. In order to check the list, the objectives can be divided into general categories: health, safety, social, political, psychological and economical effects. Many of these objectives will necessarily be part of the decision making process following radiological emergencies. Some of the objectives might be directly measured on a numerical scale and some should be further divided into sub-objectives in order to be measurable. This kind of numeric variable is called an attribute. An attribute is used to measure the performance of actions in relation to an objective. Natural attributes are, e.g., immediate deaths, cancer cases or reduction of the lifespan. An *attribute hierarchy* (*value tree*) can be useful in defining attributes and objectives. Figure 2 shows the value tree for the remedial operations for the problem in hand.

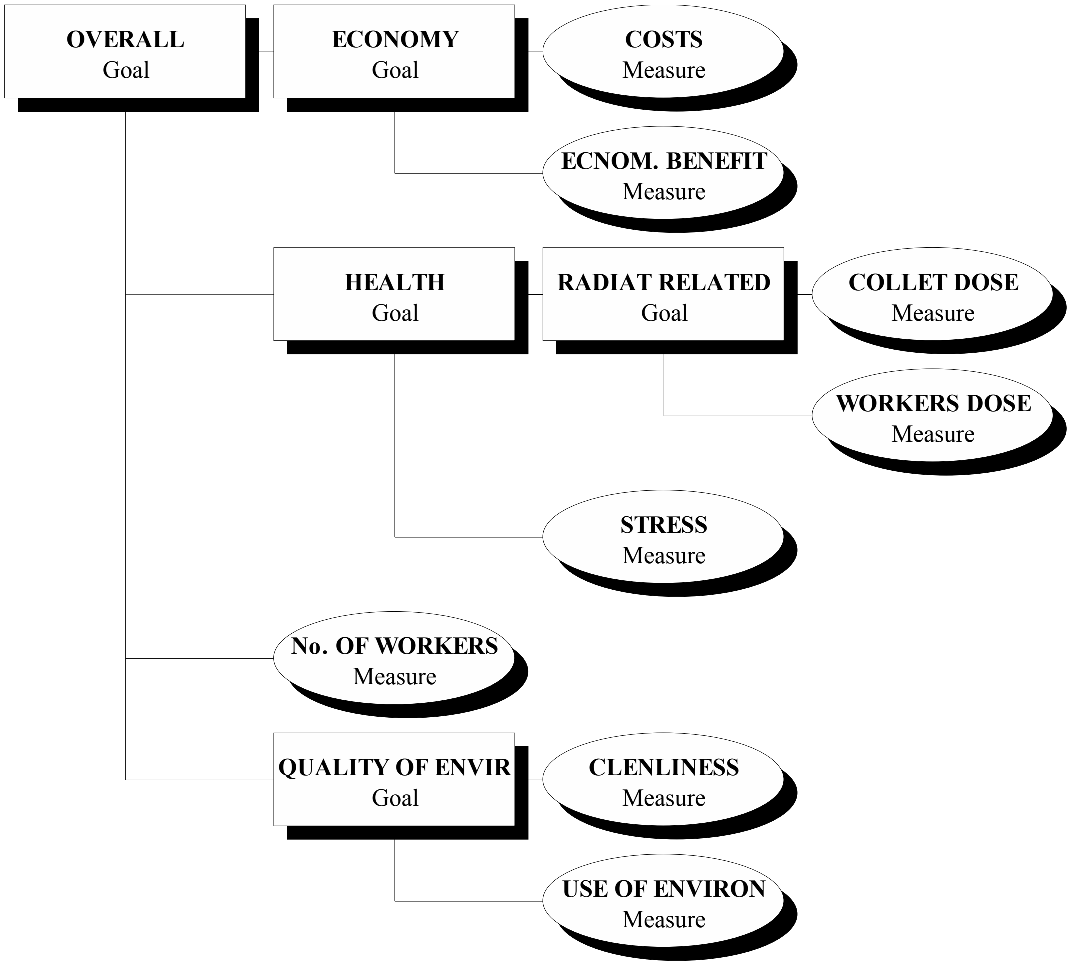


Figure 2. Hierarchy of attributes used in the decision model.

The attributes used in the analysis are defined as follows.

The effect on *health* is seen to have two components, of which radiation related health effects is further divided into two sub-attributes: these are doses to the workers and dose to the public.

Dose to the public. Because exposed individuals are not identifiable, the value of this attribute is assessed as the projected collective dose to the public (manSv). This relates to the expected number of fatal cancers caused by radiation, calculated by applying a risk factor of 5% to the dose in manSv.

Doses to the workers. Projected individual doses to the workers carrying out the recovery operations (mSv).

Number of workers carrying out the recovery operations. As initially planned the recovery operations will cause unacceptable high individual doses to the workers (several ten's of mSv). To keep the doses acceptable, i.e., below the dose limits, more workers should be employed. Thus, an objective will be to keep the number of workers as low as possible.

Stress. Psychological stress caused by radiation both to the public and workers. Stress will be decreased or increased by protective actions and it reduces the quality of life. This attribute aims to capture also the stress caused by unemployment of workers in the affected area and worry felt by land owners.

Quality of the environment. This attribute is seen to have two sub-attributes; *Cleanliness of the environments* and the *use of the environment* for refreshment. These attributes are aimed to capture the reduction in the quality of the contaminated areas and the living areas close to the contaminated forest, disposal site and around power stations burning radioactive wood.

Economic benefit. The monetary benefit to the industry and the society obtained by burning the wood as fuel (MFIM).

Costs. The monetary costs caused by implementing recovery operations. Total costs include direct costs of operations (harvesting, transportation, disposal), control of the area, loss of income and lost capital services (MFIM).

8.4.3. How the strategies perform on each attribute

Now the consequences of the actions can be assessed, i.e., how well the different actions perform for each of the lowest level attributes in the value tree. The consequences are the values of attributes in various actions, e.g., the assessed dose if action is taken and the action's monetary costs. The measurement of these two attributes is easy, because we can identify the variables representing them. However, for attributes, such as stress and quality of environment, it is more difficult to find a proxy attributes or variables that can be quantified. The techniques, which can be used to express the preferences over the values of an attribute, are *direct rating* and the use of *value functions*.

Direct rating can be used with attributes which cannot be represented by easily quantifiable variables. In this technique, the most preferred option for, e.g., stress, a value of 100 is given and the value of zero for the least preferred option. The other options are ranked between zero and 100, according to the strength of preference for one option over another in terms of stress. Although this technique seems to be robust it should be emphasized that there are methods to check the consistency of the elicited numbers. Also, numbers do not need to be precise. As will be pointed out later when discussing sensitivity analysis, the choice of an action is generally fairly robust, and often substantial changes in the figures are required before another option is preferred.

The preferences over values of an attribute can be changed numerical also by a value function. As in direct rating the most preferred option for an attribute, a value of 100 (or 1.0), is given, and the value of zero for the least preferred option. There are several methods which can be used to elicit the intermediate values to form a continuous value function. The simplest conversion, which is used in this analysis, is a straight line, where a unit change in the preference of an attribute corresponds to an equal change in value.

The assessed values of attributes for each action are given in Table III.

Table III. Values of the attributes for strategies defined in Table II.

Strategy	Collective dose to public (manSv)	Individual dose to workers (mSv)	Number of workers	Economical benefit (MFIM)	Costs of action (MFIM)
1a	5460	20	1270	120	121
1b	5380	20	1220	0	129
2a	5480	20	1230	120	119
2b	5400	20	1180	0	127
3a	5390	20	3550	166	151
3b	5370	20	3570	0	163
4	5560	0	0	0	66
5	2050	0	0	0	4710
6b	3140	20	170	0	3200

a) Wood material is burned as fuel before disposal
b) All material is disposed as such.

In assessing the collective dose to the public the external dose and intake of radionuclides in all relevant pathways were considered, i.e., the dose caused by resuspension, burning radioactive wood, using contaminated wood material and forest fire. Of these the use of contaminated wood would cause the highest doses, 3500 manSv. The inhalation dose over 70 years was considered to be small compared to intake and external dose. There are no models designed specifically for this kind of problem. Therefore, the dose calculations have to be based on expert judgments and as far as possible on the dispersion and dose prediction models developed primarily for accidents at nuclear power plant. The dose predictions were done by ARANO software package (Sa77).

The dose to each worker group in each work phase were calculated separately; felling the trees, removal of undervegetation and soil, transportation of trunks, chip and ash, and disposal of wood material or ash. The software package MATERIA was used to assess the individual doses to workers (Ma93). In most cases the estimated doses were unacceptable high, several ten's of mSv, and in these cases the number of workers was increased to keep the individual doses below 20 mSv.

The use of wood will strongly be affected by public opinion if the action to control of wood material would is taken (strategy 6b). Because the contaminated area would be commonly known, all the wood material from these areas would not be accepted by the industry. This will cause a reduction in collective dose, but at the same time will increase the monetary losses to land owners. It was estimated, that one third of wood otherwise used, i.e., if no action is taken, will be rejected.

The monetary costs of actions and also benefits were calculated using the information collected in other study of this project (cf. chapter 6), Finnish statistics and similar monetary costs assessment methods as is presented in COCO-1 report (Ha91). The costs of lost capital service and removal of trees are the main costs components.

The scales for stress and quality of the environment attributes were developed judgmentally and the values are given below in Tables IV and V. Higher score represents a more preferred actions.

Table IV. Scores of stress attribute.

Strategy	1a	1b	2a	2b	3a	3b	4	5	6b
Score	80	90	90	100	60	70	40	0	50

a) Wood material is burned as fuel before disposal
b) All material is disposed as such.

Strategy 2b was given the highest score because it treats the workers, the population and land owners fairly, offering a certain degree of decontamination and because the wood would not be burned there would be no local fallout. Also, the amount of disposed waste would be acceptable. It was felt that to reduce psychological effects it is important to take the actions shortly after the accident and at the same time to avoid too excessive actions. Strategy 5 was given the lowest score. It treats area III differently than others by offering reassurance only by controlling the access to the area, but on the other hand, it would cause lot of problems to individual land owners even if the cost of action would have to be borne by the society. Strategy 4 was seen as next least acceptable. It offers no reassurance of decontamination, although there would be no doses to the workers. The scores for other strategies were assessed according their strength of preferences using similar arguments.

Table V. Scores of quality of the environment attribute.

Strategy	1a	1b	2a	2b	3a	3b	4	5	6b
Score	100	90	80	70	90	80	20	0	50

a) Wood material is burned as fuel before disposal
b) All material is disposed as such.

Although there are sub-attributes, the cleanliness and the use of environment, below the quality of environment attribute it was thought to be appropriate to assess the scores directly to the higher level attribute, i.e., to the quality. Strategies 4 and 5 were given the worst scores because the contamination would be left untouched in the environment. The objective, the use of the environment was also in its worst position in strategy 5. The control of access (with fences) would also impair the quality of the environment. Although there would be a small release of radionuclides into the environment in strategy 1a when burning contaminated wood, it was felt that this strategy offers the best quality of the environment. The other strategies were felt to be less attractive and the assessed scores are seen in the Table V.

In the analysis the figures given above, e.g., collective doses, were transformed linearly to 0 - 1 scales and their different relative lengths are taken into account in assessing the weights on attributes (see below).

8.4.4 Trade-offs

Before we can combine the values for different attributes in order to obtain a view of overall benefits which each action has to offer, we have to assess the weights on attributes. They represent the judgment of the decision maker on the relative importance of the levels of attributes. For example, how much he/she is ready to accept doses to individual workers to avoid a certain dose to the population. When assessing a trade-off value, it should be noticed that the importance of an attribute is not only dependent on its conceptual value, such as health, but also on its *range of values*, such as the number of cancer cases. The range means the difference in values in various actions, e.g., the difference in dose when the action is taken or not taken.

Swing weighting is applied in the analysis as an assessment method for scaling constants, i.e., the trade-offs. In the method a decision maker is asked to compare a set of pairs of hypothetical actions which differ only in their values along two attribute scales until an indifferent pair of options is found. For example:

Option A: The individual dose is 20 mSv and the collective dose is 0 mmanSv.
Option B: The individual dose is 0 mSv and the collective dose is 100 mmanSv.

If the options A and B are felt to be indifferent, it can be seen that it is more preferred to avoid higher individual risks than individually low but collectively higher risk. It is estimated, that the individual doses to the population are far less than one mSv on average. If we set the weight of the collective dose to one, and taking into account the 'length' of collective dose scale, 3510 manSv, and individual dose scale, 20 mSv, this suggests a weight (5*0.001*20/3510) = 0.00003 for the individual dose scale relative to the collective dose scale.

The weights were set on other attributes using similar judgments. For example, the following indifferent (marked with ~) pair of options was elicited for the number of workers and individual dose:

(1 men; 20 mSv) ~ (100 men; 1 mSv).

This assessment together with the fact that the number of workers scale has a length of 3570 men and the worker dose scale 20 mSv, means that number of workers scale is felt 36 times as important as the individual worker dose scale of 20 mSv. Altogether six trade-offs have to be assessed in order to have a complete set of weights. The following pairs of attributes were used to assess the weights, and the indifferent options are given below:

Collective dose/costs attributes:

(2 manSv; 0 MFIM) ~ (1 manSv; 0.25 MFIM)

Costs of action/monetary benefit attributes:
(0 MFIM; 170 MFIM) ~ (170 MFIM; 0 MFIM)

Collective dose/stress attributes:
(3000 manSv; 100 Stress) ~ (2000 manSv; 0 Stress)

Stress/quality attributes:
(50 Stress; 100 Quality) ~ (100 Stress; 0 Quality).

Based on these assessments the following weights are obtained (Table VI). *Note:* The weights are normalized so that the sum of weights is one.

Table VI. Weights of attributes.

Attribute	Weight
Collective dose	0.15
Individual dose of workers	0.000004
Number of workers	0.0002
Monetary costs of action	0.76
Economic benefit	0.03
Stress	0.04
Quality of the environment	0.02

8.5. ANALYSIS OF THE MODEL

At this stage we are in position to aggregate the values to find out how well each strategy performs overall. The *Additive model* was applied simply to add together an action's weighted value scores (weighted attribute values on each action) to obtain the overall benefit:

$$v(a) = \sum_i k_i v_i(a_i),$$

where $v_i(a_i)$ are single-attribute value functions, a_i are assessed values of attributes and k_i are weighting factors. *Note:* A sufficient condition for an additive decomposition of multi-attribute value function is mutual preferential independence of the attributes. An attribute X is preferentially independent of attribute Y, if the two preference values of attribute X do not depend on the value of Y. The existence of preferential independence is normally verified during the analysis - and should, in principle, be verified. If the conditions for an additive function exist, the weights are assessed by making trade-offs between attributes as described earlier.

To make the calculations slightly easier the decision model was build using the software package LDW (Sm93). The overall scores and ranking of strategies are as is given in table VII. Strategy 1a, decontamination in areas I and II, and no restriction in area III, is just optimal. In fact, strategies 1-4 rank very close to each other. This is due to area III, which because its large area has a strong effect on attribute values. In strategies 1-4 the same action is taken in the area III.

Table VII. Overall scores for the initial analysis.

Strategy	1a	1b	2a	2b	3a	3b	4	5	6b
Overall score	0.834	0.819	0.833	0.819	0.829	0.805	0.790	0.195	0.41
Rank	1st	4th	2nd	4th	3rd	5th	6th	8th	7th

It is wise to be skeptical about the ranking of the actions, if the variation of figures used in the analysis is not analyzed with a sensitivity analysis. We have to examine how robust the choice of an alternative is to changes in the figures. In many cases sensitivity analysis also shows that the data do not need to be accurate. Large changes in these figures are often required before one action becomes more attractive than another. If this is the case, then it would be waste of effort and time to elicit the numbers accurately.

There are several techniques presented in the literature to perform a sensitivity analysis. The most straightforward analysis applied here examines the effects of varying one parameter at a time. Although the method is simple it clearly indicates which factors are important and require refined assessment.

There are lot of uncertainties in the assessment of the collective dose and monetary costs. The weights of these attributes are also high. The sensitivity analysis on the weight of costs is shown in figure 3.

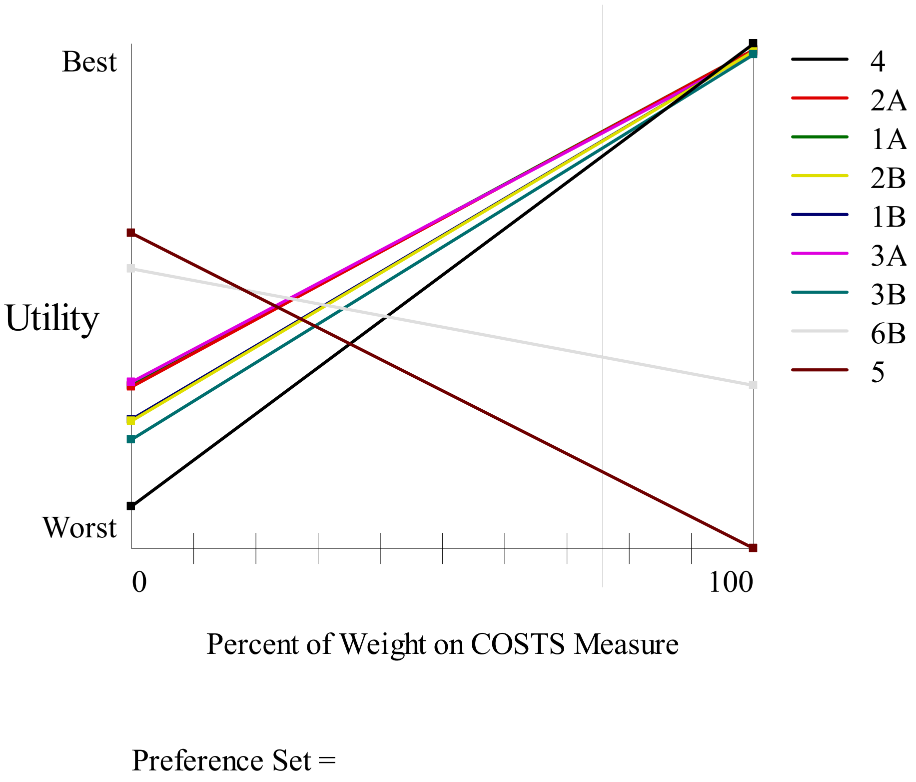
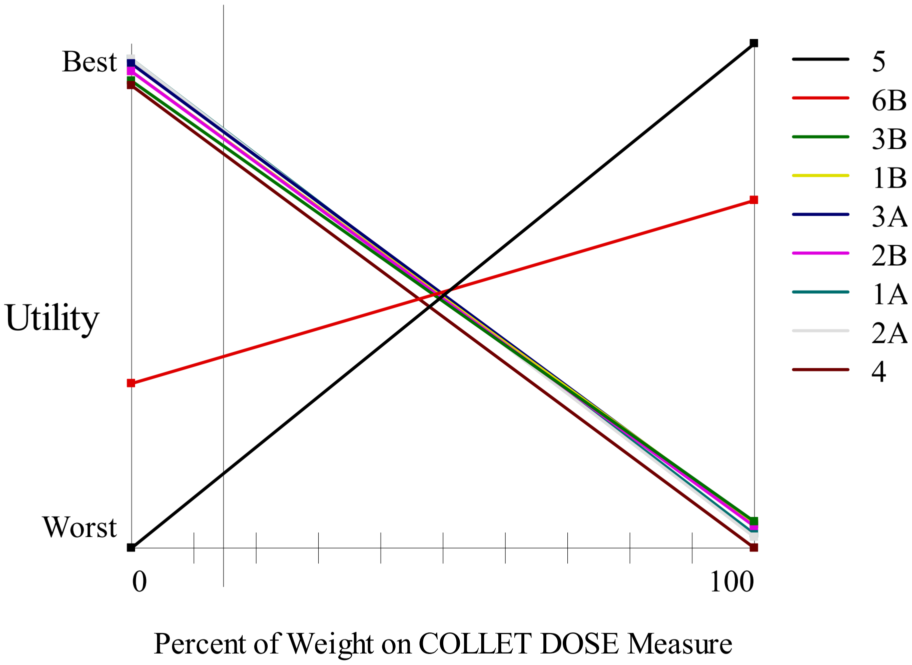


Figure 3. Sensitivity analysis on costs.

The weight on costs is about 76% of the total weight in the model and this value is marked with the vertical line in the figure 3. The overall score for each strategy against the percentage of total weight on costs are plotted with solid lines. The line with the highest intersection with the vertical line shows the optimal strategy, i.e., strategy 1a.

As the weight on costs is between 35% and 95% strategy 1a is just optimal, but below 35% strategy 6b and then strategy 5, and above 95% strategy 4 will be the best courses of action, respectively. Besides this range gives the accuracy needed in the weighting the costs attribute, it also reflects the required accuracy in the costs calculation because the 'length' of an attribute is taken into account when assessing trade-offs, on the assumption that there is consistency in costs calculation between strategies.

The sensitivity analysis on the weight of collective dose is shown in figure 4. With the present weight (15%) on dose, the strategy 1a ranks best. The highest value of the collective dose was obtained in the pathway where the contaminated wood is used without restrictions. It was felt that this might be too high. The analysis suggests that substantial changes would be required before the strategies 5 and 6 become more preferred.



Preference Set =

Figure 4. The sensitivity analysis on collective dose.

Because strategies 5 and 6 seem not to be the best course of action the analysis was revised omitting these strategies from the analysis. Doing this the effect of decontamination on decision is more clearly seen. The same trade-offs is used as earlier, but because the 'length' of scales are changed the following weights given in Table VIII are obtained:

Table VIII. Weights of attributes in revised analysis.

Attribute	Weight
Collective dose	0.086
Individual dose of workers	0.00003
Number of workers	0.0014
Monetary costs of action	0.16
Economic benefit	0.23
Stress	0.34
Quality of the environment	0.17

The ranking of strategies for analysis based upon above-mentioned weights are given in Table IX.

Table IX. Overall scores for the revised analysis.

Strategy	1a	1b	2a	2b	3a	3b	4
Overall score	0.73	0.60	0.72	0.59	0.69	0.47	0.33
Rank	1st	4th	2nd	5th	3rd	6th	7th

The ranking of strategies is - as it should be - the same as in the initial analysis. However, the difference between the strategies is more clearly seen. Now the sensitivity analysis on the weight of collective dose is as is shown in figure 5.

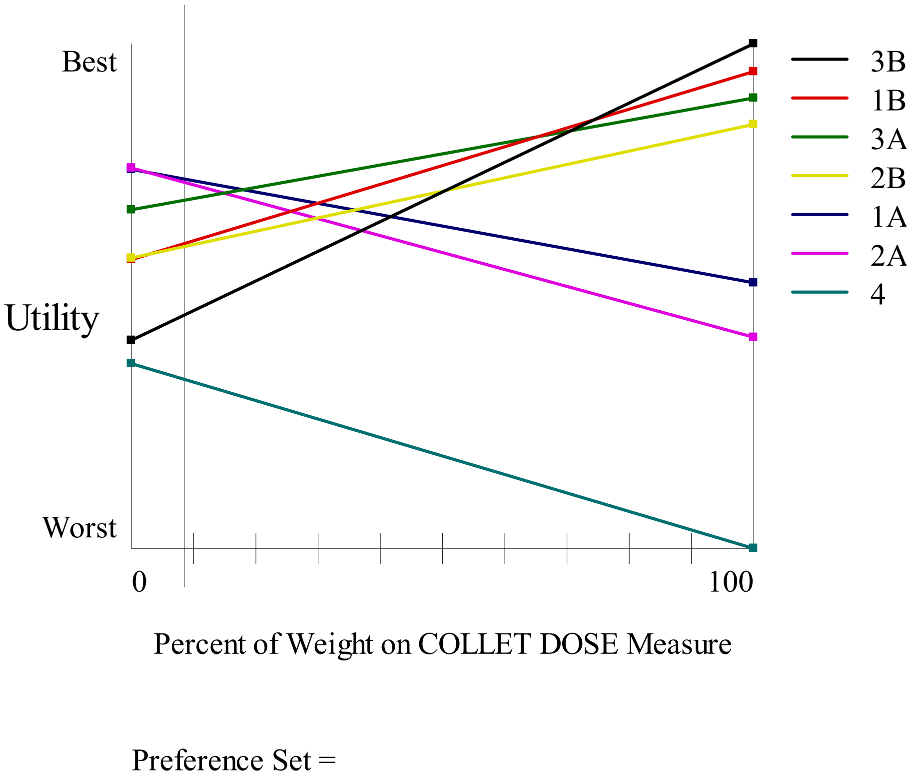


Figure 5. Sensitivity analysis on collective dose. Strategies 5 and 6 are omitted from the analysis.

The difference between stetegies 1a, 2a and 3a is not large and the analysis suggests that the best course of action could be found in this group of strategies. There should be modifications in strategies 1b, 2b and 3b, or changes in numbers or trade-offs before this group of action will become more attractive. As is shown in figure 5 strategies 2b and 4 are never optimal actions considering the values and the trade-offs used in the analysis.

Before final conclusion on the action it is useful to gain further understanding considering stress attribute. It was unpleasant to assess numbers on this attribute and because the weight on this attribute is also high, its effect on decision should be further considered. This could be done with figure 6.

Figure 6 shows that increasing scores go with increasing preferences. The figure plots the overall utility for all other effects excluding stress against stress. In principle the strategy represented by a cross in the upper right corner is most preferred. On the upper right boundary (Pareto or efficient frontier) lie strategies 1a, 2a, 3a and 2b in this diagram. The optimal choice depends on value put on stress. As the value increases from 0 to 100 the optimality moves from strategy 3a to strategy 1a and through 2a to 2b. These strategies offer better choice, i.e., they dominate strategies 1b, 3b and 4 which can never be optimal without changes in their scores and weights.

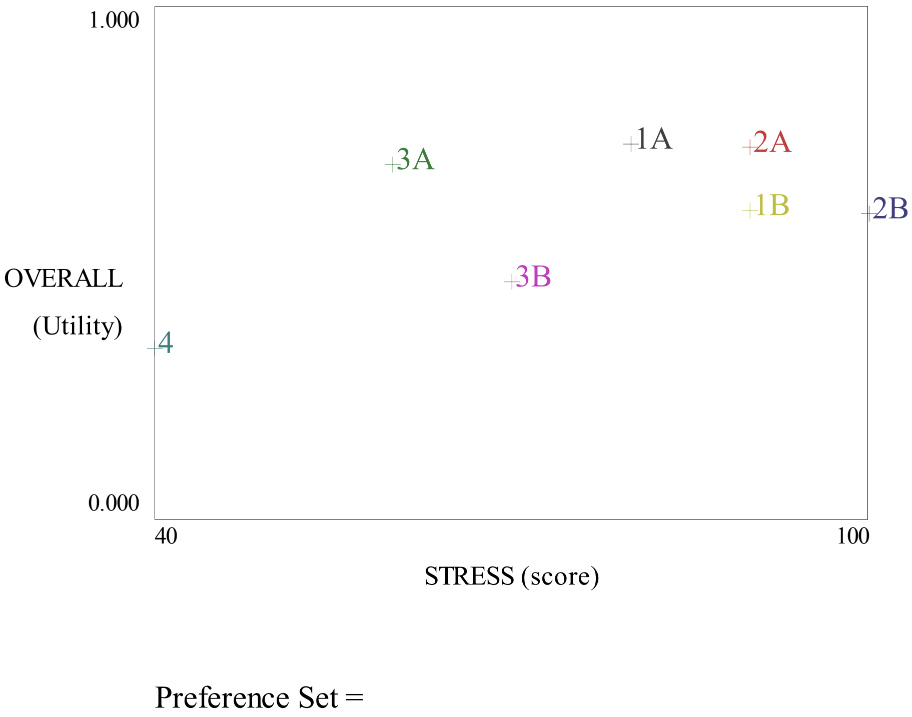


Figure 6. Plot of utility against stress.

8.6. CONCLUSIONS

The objective of this study has been to give an illustration of decision analysis and the application of the analysis when planning countermeasures for forest areas in order to mitigate the consequences of a nuclear accident. The basic principles of radiation protection are based on the justification and optimization of protective actions. Decision analysis, although closely entwined with these principles, does not interpret the results with this terminology. The aim of decision analysis is to find the best solution to a problem based on the rationality of the decision maker(s). However, the result of decision analysis can be translated to correspond to the basic principles of radiation protection.

At the beginning of a decision analysis all feasible protective actions are defined, including the action of doing nothing. When assessing the justification of protective actions, the present situation forms the basis to which the actions are compared, with respect to the preferences of society represented by a decision maker. The preferences and trade-offs - the judgmental inputs to analysis - form the basis for justification. A protective action is justified if the values connected to it are greater than those of no action.

The optimization of the intervention is achieved by ranking all feasible actions. The action with the highest ranking will produce the maximum benefit. In optimization it is thus assumed that all actions and attributes are defined at the beginning of an analysis. In practice, however, it is not possible to define all actions before making some preliminary numerical assessments and running through some rough calculations to gain a feeling for what numbers are important and require refined assessment. The optimization of intervention means this iterative process of maximization of protection in all its essentials. The setting of an intervention level in an accident situation or in planning of the intervention levels is seldom a purely mathematical problem.

The decision analysis performed suggest that a strategy somewhere between 1a and 2a would be the best course of action to be taken in the given situation. There would be a few differences between these strategies. The treatment of areas are quite the same: in area II trees would be removed during the same season and in area III 'doing nothing' would be taken in both strategies. No action in area III was deemed to be more preferred to the actions 'control of access' or 'control of wood material'. In the area I the trees and undervegetation are removed and the only difference between strategies 1 and 2 is the removal of soil in strategy 1. Also, strategy 3a could be considered as an action. In all strategies the removed trees would be burned as fuel.

There are different preferences connected to the values of attributes. Therefore, *the values of attributes and trade-offs are subjective*, not objective. Expressing the value may be both unpleasant and difficult, but often it is very crucial when assessing an intervention level. Since the values are subjective, no universal values exist. The values are related to the unique problem, and in addition, they change according to opinions and resources. In addition, people have strong feelings and beliefs about these values, which typically are not numerically quantified and do not exist in monetary form. Careful structuring of the problem is necessary to identify the underlying multidimensional values, attitudes to risk and trade-offs related to the problem. To create more insight more research is needed, specially on the less quantifiable factors.

The analysis represented above is based on hypothetical accident. In real problem depending on prevailing situation where the fallout area could be located in the map, more strategies would have to be considered. Also, the factors entering the decision are dependent on situation. Thus, the results of the performed analysis could not be applied in real situation as such, but the actions and factors should be revised and the calculations redone. The strategies found appropriate in the analyzed situation might turn out not to be the most preferred in the real problem, however, they might well indicate the course of actions to be considered.

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ACKNOWLEGEMENT

We would like to thank Dr. Jukka Lehto for his participation in the analysis, and for his advice and comments on the draft manuscript.